JULY, 1960

Welding Journal

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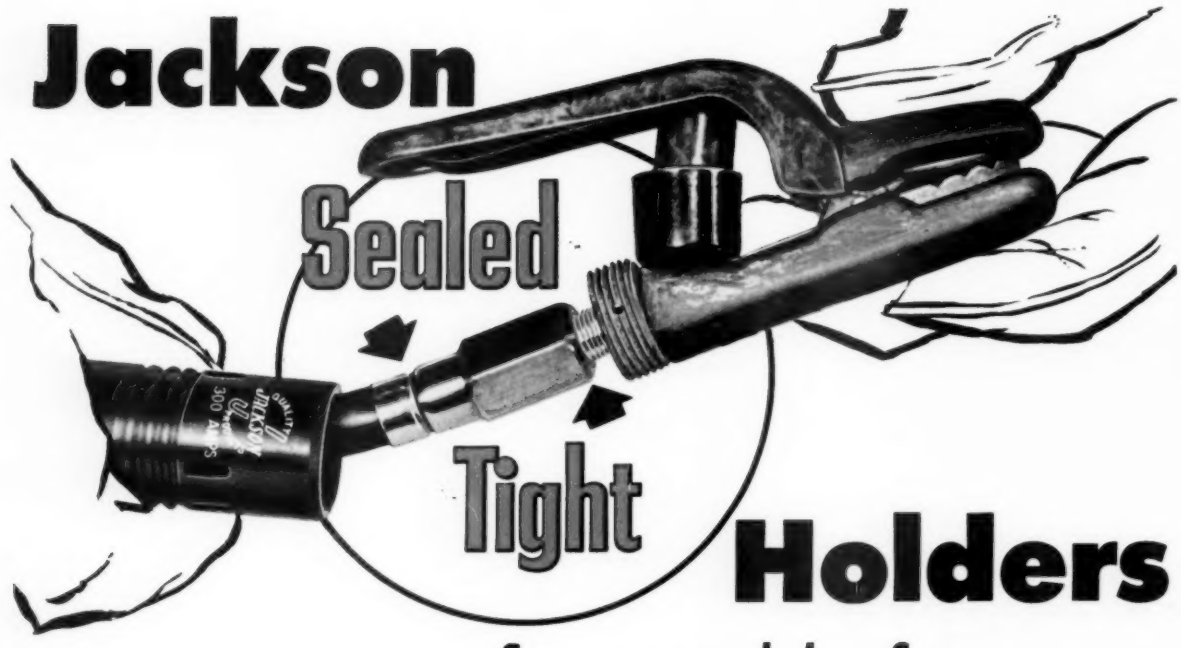
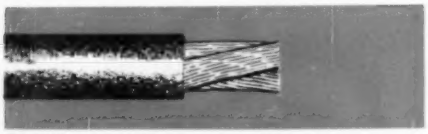
OFFICIAL PUBLICATION OF THE AMERICAN WELDING SOCIETY

Jackson Sealed Tight Holders

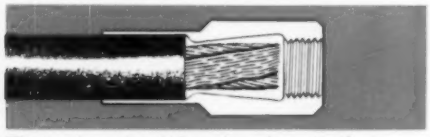


for trouble-free connections

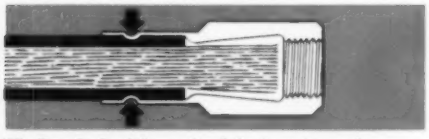
■ *Strip back the cable jacket–*



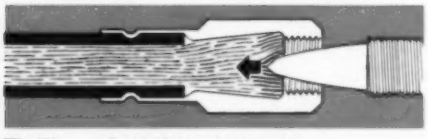
■ *Slide on the connection nut–*



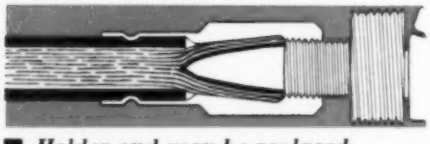
■ *Seal nut with crimping tool–*



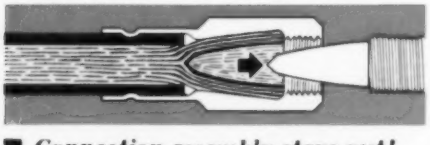
■ *Push holder stud into strands–*



■ *Wrench tightly into place–*



■ *Holder end may be replaced–*



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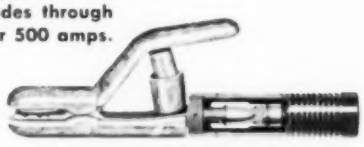

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PRESS-TIME NEWS ... about ... People ... Welding ... Products

James F. Lincoln Receives Sullivant Medal

Presented once every five years in recognition of an "admittedly notable achievement" in the arts and sciences by an alumnus or faculty member, the Joseph Sullivant Medal is one of Ohio State University's highest honors. This award was made to James Finney Lincoln, 77-year-old chairman of the board of The Lincoln Electric Co., Cleveland, Ohio.

Mr. Lincoln—engineer, inventor, economist and businessman—is perhaps best known for his human-relations philosophy as it concerns the labor-management field. He is author of the book *Lincoln's Incentive System* which sets forth his ideas on this subject.

Under his direction, the Lincoln company has encouraged a customer-concerned attitude in its workers, resulting in an extraordinarily efficient production team. From a modest beginning making motors, the company has grown to become the world's largest manufacturer of arc-welding equipment.

James F. Lincoln

The James F. Lincoln Welding Foundation, which has sponsored $250,000 in awards designed to stimulate scientific interest in and to promote the arc-welding industry, was founded in his honor.

Welding Research Council Appoints Staff Officers

The Welding Research Council of the Engineering Foundation has announced the appointment of Kenneth H. Koopman as director to succeed William Spraragen who retired on May 20th. Charles F. Larson, Jr., was appointed secretary of the Council.

Mr. Koopman brings to his new post an extensive background in metallurgy and in the research and development of many welding processes in use today. A metallurgical engineer from Rensselaer Polytechnic Institute, his career includes service with Bethlehem Steel Corp., Union Carbide Corp. (Niagara Falls and Linde Development Laboratories at Newark, N. J.) and General Electric Co., Knolls Atomic Power Laboratory. In 1958 he received his masters degree in metallurgy and was appointed assistant director of WRC and served as executive secretary of the Pressure Vessel Research Committee. He has been active in AWS, serving as chairman of the Niagara Frontier and of the New Jersey Sections as well as holding other offices. He has presented several papers before AWS and ASM meetings.

Mr. Larson graduated from Purdue University in 1958 and joined the staff of the Council as secretary in March 1960. He was previously employed by Combustion Engineering, Inc., where he did work on pressure vessel research.

Noted Member Passes Away

Royal D. Thomas, chairman of the board of Arcos Corp. and one of the founders of the AMERICAN WELDING SOCIETY, died of a heart attack on May 28th in Tokyo, Japan, while he and his wife were on a tour of the Far East.

Born in Syracuse, N. Y., in 1882, and raised in Pittsburgh, Mr. Thomas was graduated with a degree in Electrical Engineering from Cornell University in 1906. He moved from Pittsburgh to Philadelphia in 1915, while employed by the Bell Telephone Co. Shortly after World War I, during which he was assigned to training of signal corpsmen, he began his own business as R. D. Thomas & Co., selling arc welding equipment and supplies.

In 1928, he was made vice-president and general manager of Arcos Inc., which in 1936 he merged with R. D. Thomas & Co. to form Arcos Corp. Until 1957 he served as president and thereafter as chairman of the board of directors. Under his leadership, Arcos became a leading U. S. manufacturer of stainless and low-alloy arc-welding electrodes.

Mr. Thomas helped to found the AMERICAN WELDING SOCIETY in 1919. Since then he has been active in the Philadelphia Section and in the national organization. At the 41st Annual Meeting of the SOCIETY, in Los Angeles in April, he was made an honorary member. At the same time, his son, R. David Thomas, Jr., now president of Arcos Corp., was installed as AWS president.

Royal D. Thomas

The passing of Royal D. Thomas gives cause for deep sorrow. To his family and to the many friends who knew him as an active member from the very first days of AWS, the Welding Journal editors extend their sympathy.

"For the ultimate flexibility in automatic welding, don't 'marry' one particular process."

Consider the future. Select equipment that keeps ahead of obsolescence. Today you may weld mild steel. Next year it may be high strength steel, or perhaps aluminum. Five years from now...who knows? With new welding advances being made every day, you must stay ahead of the field."

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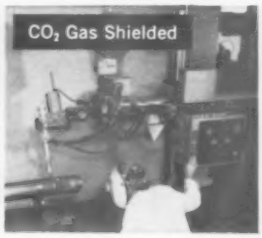

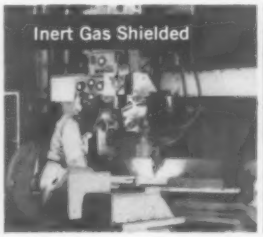

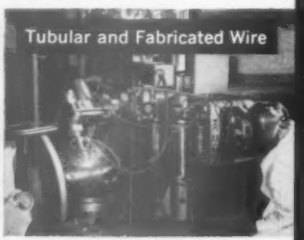

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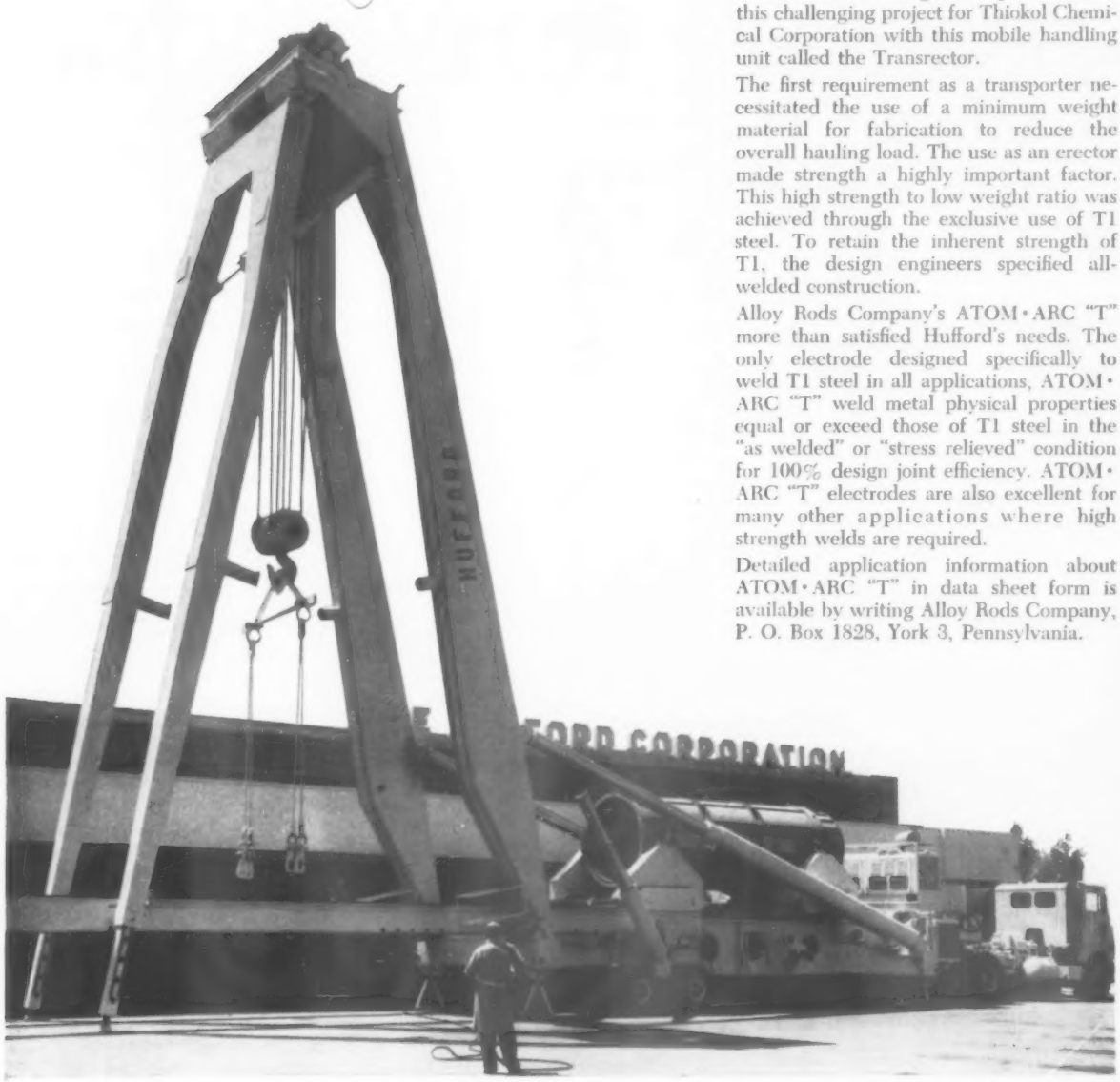
The 50-ton runner for one of the largest reversible pump-turbines ever built was made by welding cast-steel buckets to crown and runner band. Stainless cladding protects lower portion of buckets

Largest automobile-carrying freight car, this 83-ft, three-level job just clears 16 ft-10 1/4 in. above rail, loaded. Built by Pullman Standard at Michigan City, Ind., in joint effort with Chrysler Corp. and Frisco Railroad

An all-welded aluminum mine car weighs 50% less and resists corrosive action of sulfur in coal. Made of 5083 plate and 6061 extrusions by Irwin-Sensenich Corp., Irwin, Pa. (Courtesy Kaiser Aluminum & Chemical Corp.)

MISSILE AGE PAUL BUNYAN LIFTS 80,000 POUNDS WITH THE STRENGTH OF ATOM·ARC 'T'



Hufford Corporation specified all-welded construction for maximum strength, minimum weight

Transporting 80,000 pound rocket engine units and erecting them on test stands requires equipment that is unusual both in design and strength properties. Hufford Division of the Siegler Corporation met this challenging project for Thiokol Chemical Corporation with this mobile handling unit called the Transrector.

The first requirement as a transporter necessitated the use of a minimum weight material for fabrication to reduce the overall hauling load. The use as an erector made strength a highly important factor. This high strength to low weight ratio was achieved through the exclusive use of T1 steel. To retain the inherent strength of T1, the design engineers specified all-welded construction.

Alloy Rods Company's ATOM·ARC "T" more than satisfied Hufford's needs. The only electrode designed specifically to weld T1 steel in all applications, ATOM·ARC "T" weld metal physical properties equal or exceed those of T1 steel in the "as welded" or "stress relieved" condition for 100% design joint efficiency. ATOM·ARC "T" electrodes are also excellent for many other applications where high strength welds are required.

Detailed application information about ATOM·ARC "T" in data sheet form is available by writing Alloy Rods Company, P. O. Box 1828, York 3, Pennsylvania.

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WORLD-WIDE WELDING NEWS

By Gerard E. Claussen

FRANCE

Dr. Daniel Seferian, one of the leading French welding metallurgists, died at the age of 59 on Sept. 29, 1959. He graduated from the St. Etienne College of Mines in 1927 and worked with the French Institute of Welding until 1945. During that time he completed important researches on nitrides in steel weld metal and on the physics of gas-welding flames. In 1941 he received the gold medal of the French Society for Encouragement of Industry for his contributions to the science of welding. After seven years with other firms, he joined the Sarazin Co. in 1952 and served as head of electrode research. In collaboration with Marcel Moneyron of that firm he published papers on the effect of hydrogen on impact value, and on the classification of electrodes in terms of impact transition temperature. He was author of several books on welding.

ITALY

A description of advances in manufacture of steel pipe 16 to 24 in. diam, referred, in *La Metallurgia Italiana* for July 1959, to an induction welding process operating at 450,000 cycles. Pipe of $^{5}/_{16}$-in. wall was welded with 140 kw. Reference was made to a Russian claim for submerged-arc welding large diameter pipe at 200 ipm. An Italian firm developed a television set for controlling the welding of the inside bead.

The August issue of this magazine contains 15 articles on nondestructive testing. An article from Fiat illustrates the ultrasonic testing of butt and fillet welds.

The Italian Welding Society's annual report for 1958 states that their staff of 20 consists of 5 engineers, 1 accountant, 2 industrial experts, 8 technicians and 4 stenographers. Of the 27,000 man-hours available, 45% is devoted to technical advisory work, 12% to teaching and the remainder to editing the magazine and administrative duties. A proposed classification is being prepared for submerged-arc welding fluxes.

Dr. GERARD E. CLAUSSEN is associated with Arcrods Corporation, Sparrows Point, Md.

NETHERLANDS

The September 1959 issue of *Lastechniek* celebrated the 25th anniversary of the Netherlands Institute of Welding. In 1921 The Mechanics Group of the Society for Promotion of Manual Proficiency advertised courses in oxyacetylene-welding. On Feb. 8, 1922, representatives of eight firms organized the Netherlands Acetylene Society at the initiative of R. A. Gorter, director of the Safety Museum in Amsterdam. Through the years arc welding became an important part of the Society's activities and the name was changed to Netherlands Welding Society in 1934. Membership has grown from 800 in 1935 to 7000 today. The Society has held 12 welding symposia, publishes a magazine, has active research and education committees, issues diplomas to welding operators successfully passing its courses and holds welding expositions. The theme of the 1960 welding symposium is "Man in the World of Welding."

Copper Cladding

This anniversary issue contains 18 short articles on welding processes, inspection, planning and shop welding. An article on the welding of $^{1}/_{2}$-in. deoxidized copper plate stated that a half-and-half mixture of argon and helium was used (50 cfh) with $^{3}/_{32}$-in. electrode at 650 amp straight polarity, 30–31 v constant potential rectifier. The electrode contained 1% tin and preheat was 840° F. The copper served as cladding on a steel vessel.

RUSSIA

The August 1959 issue of the Russian magazine, *Svarachnoe Proizvodstvo*, contains the following papers:

1. Butt welds are made in pipe by establishing an arc between the pipes and causing the arc to move around the circumference of the pipe by means of a magnetic field. Using the motor principle, a butt weld was made in steel pipe $12^{3}/_{4}$-in. OD, $^{3}/_{8}$-in. wall at 1150 amp, 40 v in 120 to 150 sec with 6900 amp turns magnetization. The pipe was stationary except at push up, and argon was essential to improve arc starting and stability. Flanged joints were welded by using a water-cooled tube surrounding the joint, the arc being struck between the joint and the water-cooled tube.

2. Tantalum sheets 0.02 to 0.15 in. thick were welded with tungsten electrode on d-c straight polarity with 99.98% argon. The tungsten electrode was 0.04 to 0.12 in. diam, the current rising from 65 to 350 amp in the thickness range. The welds had 74,000 to 92,000 psi tensile strength, 125 to 180-deg bend angle, and good corrosion resistance in 32% HNO_3 and 20% H_2SO_4.

3. Free energy calculations showed that the partial pressure of hydrogen in the gas phase of the submerged welding arc decreased as oxygen was added as MnO_2 or $CaCO_3$, and as fluorine was added, provided fluorine was not given the opportunity to combine with silicon. A bonded flux consisting of 60% MnO_2, 10% CaF_2, 20% SiO_2, 10% of 75% ferrosilicon and calcined 1 to $1^{1}/_{2}$ hr at 1110–1200° F, produced sound welds in mild steel at 450 amp ac, 32–33 v, 21 ipm, in the presence of $^{1}/_{2}$ g of rust in 4 in. of weld.

4. The cold cracking of air-hardening steels was studied by means of a jig which permitted a brief resistance heating of a notched specimen followed by cooling and straining at rates from 0.06 to 0.00006 in./sec. As the cooling rate increased from 5 to 360° F per sec, intergranular cracking oc-

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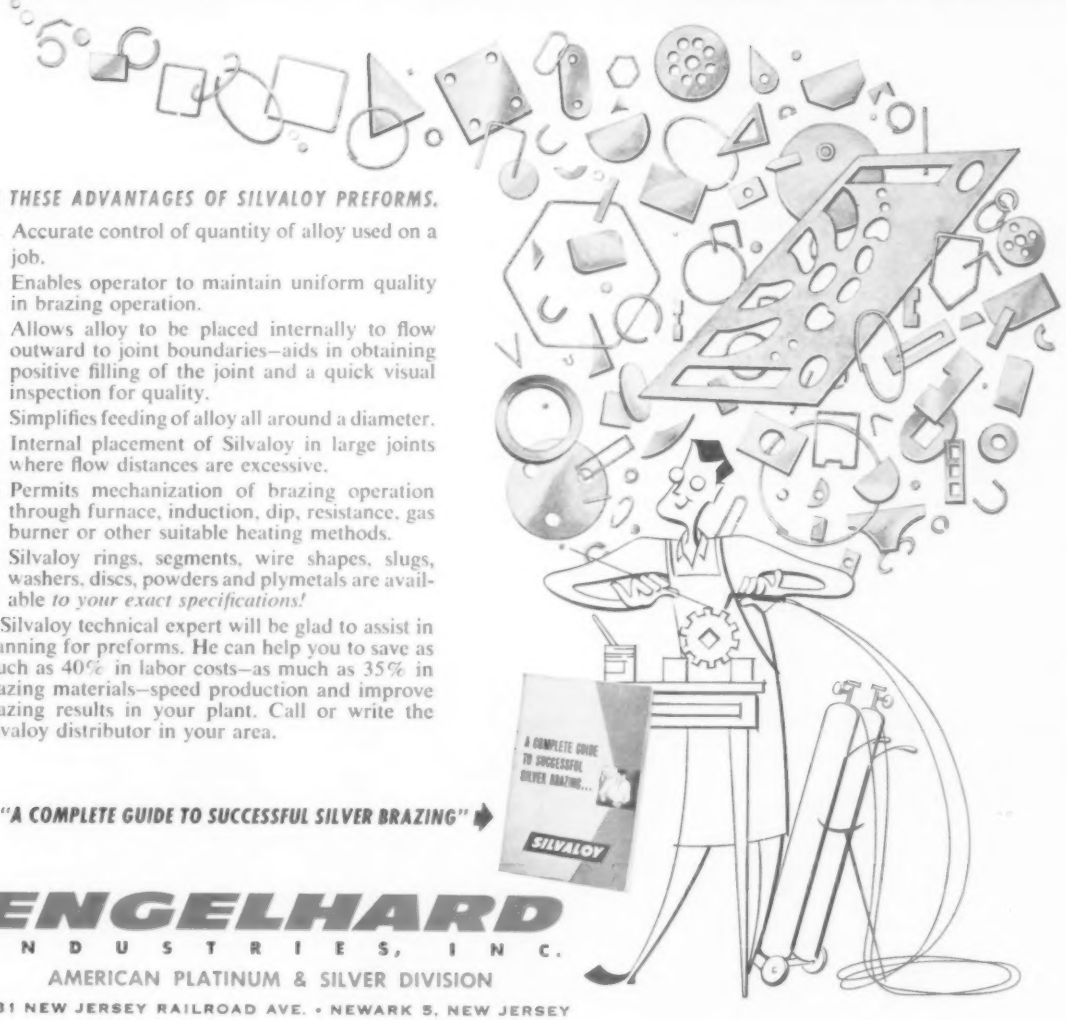

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curred to an increasing extent in the austenite grain boundaries during transformation to martensite. Cracking was more pronounced at the slower speeds of straining. The author applied Zener's ideas on relaxation with simultaneous increase in normal stress to explain the observations.

5. Arc welding in CO_2 with magnetizable flux consisting of iron, ferro-titanium, CaF_2 and manganese ore was found to produce satisfactory weld contours and low spatter. A mild steel wire 0.078 in. diam was used at 300 to 400 amp reverse polarity. Recovery of Mn and Si in the weld increased with increase in current and with decrease in size of flux particles. Smaller particles adhered to the electrode better than large.

6. The flash welding of flat bars to form rings for roller bearing races was done at the rate of 125 rings per hour. Two steels were used: one similar to SAE 52100, the other contained 0.21% C, 1.0% Mn, 0.3% Si, 1.2% Cr and 0.07% Ti. The flat strip was $1^3/_{16}$ in. wide, $^1/_2$ in. thick in one instance and the rings were 5 in. diam.

7. Static and fatigue tests were made on shear and tear specimens of spot welds in steel 0.032-, 0.059- and $^1/_8$-in. thick containing 0.30% C, 1% Mn, 1% Si and 1% Cr. Heat treatment in the machine eliminated the need for furnace heat treatment.

8. The application of transistors to automatic arc-welding control circuits is described.

9. Torch tips for welding and cutting with natural gas are described.

10. An image intensifier tube for visual radiographic inspection is described.

11. The Russian representatives on the committees of the IIW are listed.

12. A speaker at a welding economics conference in Gorky in March 1959 stated that 60% of ship welding and 70 to 80% of welding for cheimcal equipment is performed by the automatic and semiautomatic submerged-arc process.

WEST GERMANY

The West German welding magazine, *Schweissen und Schneiden*, for August 1959 contains the following articles:

1. The qualification of welders has been greatly assisted by German Standard DIN 8560, which utilizes reduced-section tension and bend specimens. Frequency charts and punch-card systems for recording training results are explained.

2. Fatigue tests showed that the best type of joint for pipe-to-header welding was a full insertion type with the header being beveled.

3. The application of semiautomatic welding to the butt welds of pressure vessels in $^5/_8$-in. mild steel required (*a*) clean joint preparation with 30-deg included angle, (*b*) holding the torch as nearly vertical as possible, the gas cup being $^5/_8$ in. above the puddle, (*c*) short arc, (*d*) dry gas, not less than 98% pure CO_2 (*e*) clean nozzle and wire conduit. The chief source of porosity was holding the torch at an oblique angle.

4. White-heart malleable cast iron can be welded satisfactorily by flash welding and less satisfactorily by arc welding. The welds have better properties than could be achieved on black-heart malleable at the Duisburg welding laboratory. Gas welding was least satisfactory, but the type of electrode and filler rod was not mentioned.

Friction Welding

The September issue featured an article on friction welding of aluminum and copper. Instead of rotating the parts, one part was held stationary while the other part was pressed tightly against it. The part was then turned 180 to 360 deg before the pressure was released. Good joints were secured with aluminum tubing 0.20-in. OD, 0.08-in. ID, bearing against an aluminum flange. The pressure was 8500 psi, the coefficient of friction being 0.91 and the shear strength 5200 psi. Under similar conditions no success was achieved in welding copper.

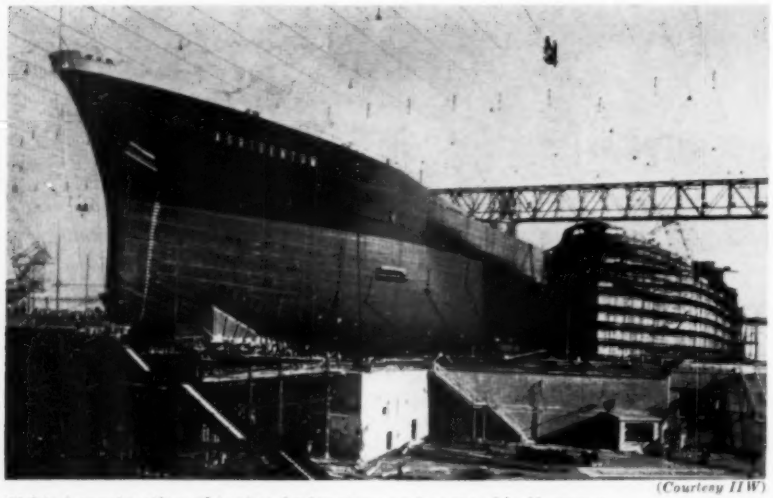
An analysis of operating costs of transformers rectifiers and motor generators for arc welding showed that the cost of current is a useful criterion. Current cost was lowest for a transformer but depended a great deal on lubrication and general maintenance.

SWEDEN

The effect of ferrite content on sigma embrittlement of 19% Cr – 9% Ni – 1.5% Mo stainless-steel weld metal, according to an article in the Swedish magazine, *Svetsaren* (No. 2, 1959), is very marked. If there is more than 7 or 8% ferrite, it transforms to a network of sigma phase which may lower the notch impact value to as little as one-tenth of the value for as-welded metal. Smaller amounts of ferrite form discontinuous sigma, which has little effect on mechanical properties. Corrosion tests in 65% nitric acid were made on weld metal containing 19% Cr, 9% Ni, 2% Mo, with 12% ferrite. Heating the weld 2 hr at 1380° F, caused a rapid increase in corrosion, while after 25 hr at 1380° F, corrosion fell to a negligible value. Diffusion of aluminum was believed to explain this result.

At a conference in Yugoslavia on arsenic, copper and other trace elements in ores, pig irons and steels, one paper described Kinzel tests on normalized steels containing 0.16% C with up to 0.4% Cu, 0.17% As and 0.10% Sb. The three elements had no effect on the Kinzel test results.

ITALY



(Courtesy IIW)

Welded construction of tanker Agrigentum and cargo ship Hermosa

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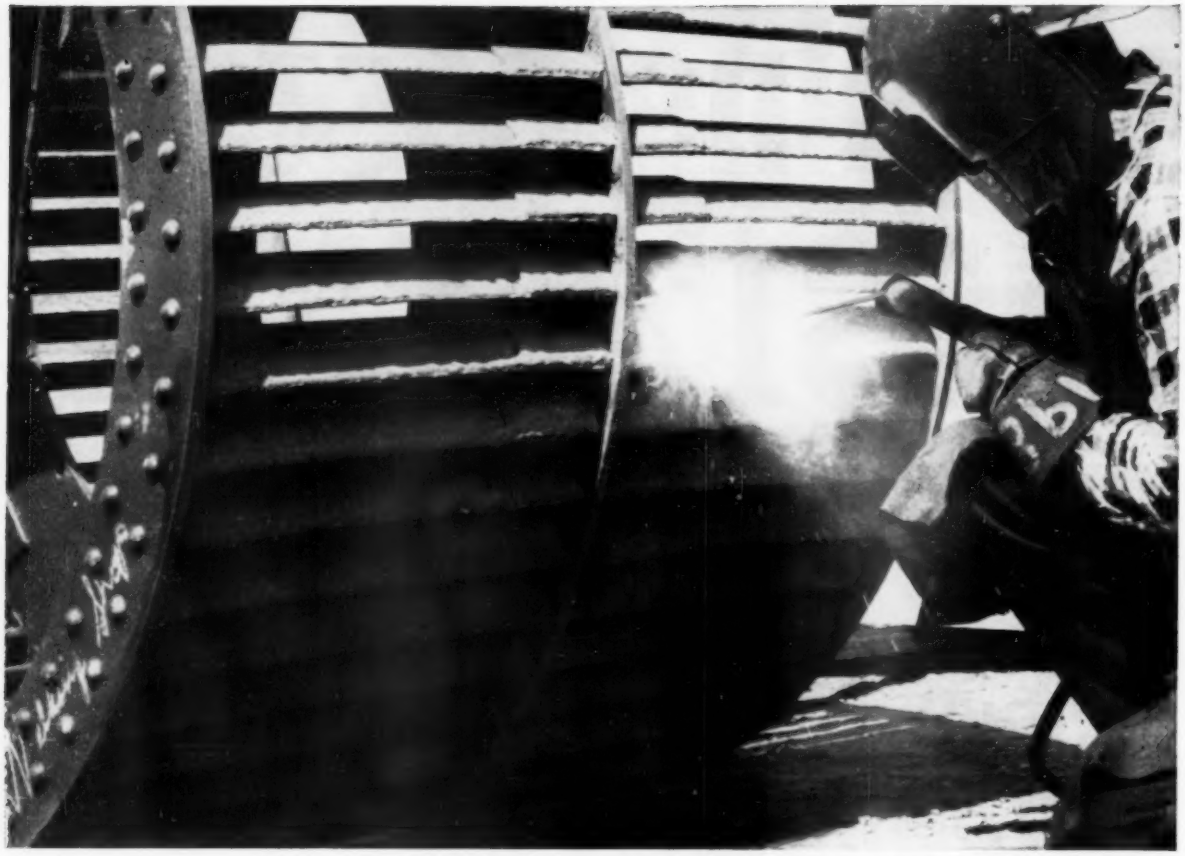

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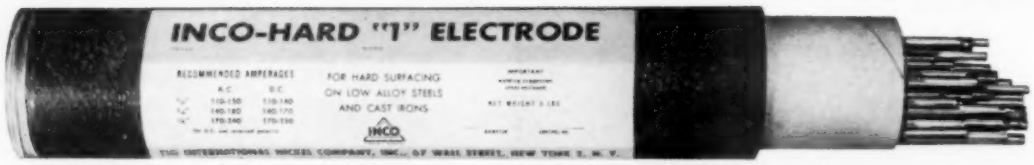

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The greatest value of any engineering group lies ultimately in its service to society. Without this service, such a group is little more than a social club. In the AMERICAN WELDING SOCIETY, for instance, a great service is performed by the development and promulgation of codes, standards, recommended practices and other technical publications. It is not generally known that the technical activities of AWS are conducted by more than ninety committees totaling over five hundred men who give their time in a spirit of public service. One must add the contribution of individual authors and the important cooperation received from other organizations. But what is the value of this activity? What is the purpose of the vast effort?

Certainly the wealth of published information poured forth from this source could not be equaled by the largest corporation. A more complete and authoritative source of welding technology could not be obtained elsewhere. As to the codes, they not only serve to protect life and property but are the very foundation of our mass-production economy. Without standards of quality in workmanship and materials, who could design a structure with reasonable assurance of safety or even adequacy? Without the uniformity of codes, how would the manufacturer of today satisfy the myriad demands of his customers? Safety, uniformity, economy and assurance are the basic values that these codes strive to attain.

It is fortunate indeed that the AMERICAN WELDING SOCIETY can continue to count on this type of service from its members and other cooperating groups. As a result, a great deal of information is easily available for the use of all who are interested. It should be to every welding man's advantage to obtain these publications, from time to time, for his personal library on welding. As an outstanding engineer, the Hon. Herbert E. Hoover, said not long ago, "These societies also constitute a gigantic postgraduate course . . . that continues all their professional lives . . . Their findings are printed for all the world to see."

John J. MacKinney
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Program aimed at developing mechanized field-welding operations for petroleum pipe-line construction results in satisfactory

Induction-Pressure Welding

of Girth Joints in Steel Pipe

BY R. L. KOPPENHOFER, W. J. LEWIS, G. E. FAULKNER, P. J. RIEPPEL AND H. C. COOK

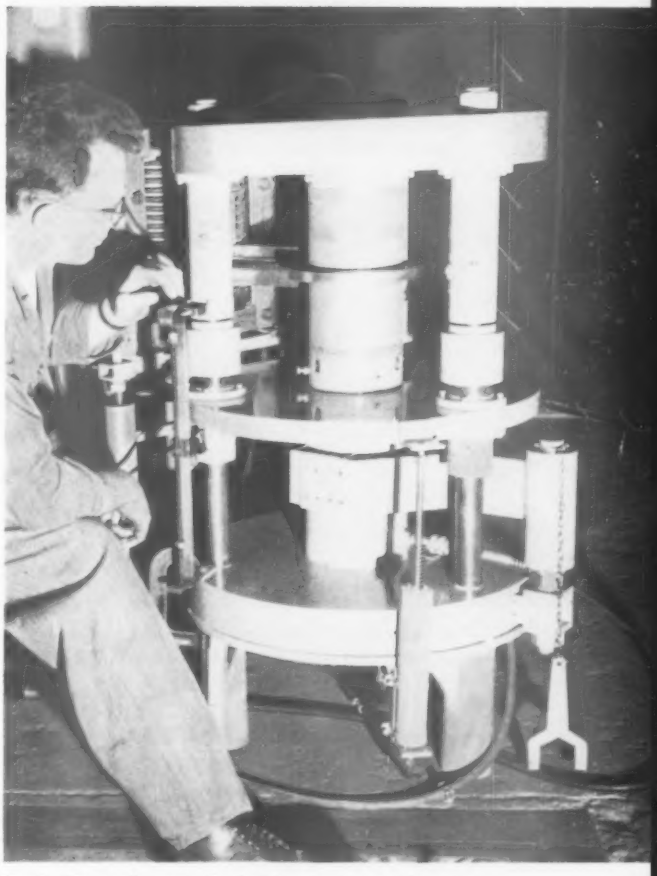


Fig. 1—Hydraulic press for holding and upsetting pipe during welding

Introduction

Pipe-line owners and fabricators have wanted to use mechanized girth-welding operations for many years. They have not had, however, a process that could be used satisfactorily to weld pipes in the fixed position at the rates required for pipe-line fabrication.

In a program aimed at developing mechanized field-welding operations for pipe-line construction, Esso Research and Engineering Co. undertook a research program at Battelle to investigate induction-pressure welding for use in pipe-line construction. This process was studied because:

1. It can be used to weld pipe in the fixed position.
2. Welding rates are potentially high.
3. Gas and induction-pressure welding have proved satisfactory for making high-quality welds for other applications.
4. Mechanized gas-pressure welding had previously been tried for pipe-line construction.

Induction-pressure welds are made by the application of heat and pressure to the ends of the pipe being welded. In making these welds, the ends of the pipes are butted together under pressure and heated by induction. Heating is restricted to a small width on either side of the abutting surfaces by the use of a suitable induction coil that is concentric with the pipe. Heating occurs when high-frequency alternating current is supplied to the coil. The flow of current sets up a magnetic field within the coil which, in turn, induces an electric current in the pipe. The I^2R heat generated by the flow of this induced current heats the pipe.

R. L. KOPPENHOFER, W. J. LEWIS, G. E. FAULKNER, and P. J. RIEPPEL are associated with the Metals Joining Division of Battelle Memorial Institute, Columbus, Ohio, and H. C. COOK is associated with Esso Research & Engineering Co., Elizabeth, N. J.

Paper presented at AWS 41st Annual Meeting held in Los Angeles, Calif., April 25-29, 1960.

As the pipe ends are heated to temperatures above about 2300° F, the pressure exerted on the pipes deforms or upsets the abutting pipe ends. By achieving intimate contact at high temperatures, grain growth, diffusion and coalescence occur across the interface resulting in strong welds.

During the research program, procedures were established for induction-pressure welding girth joints that easily passed API specifications.

Materials and Equipment

Welding studies were made on Grade B, ASTM A-53, $6^{5}/_{8}$-in. OD 0.280-in. wall welded-steel pipe. Prior to welding, the ends of the pipe were machined to obtain smooth clean ends. The pipes were welded in a hydraulic-operated press shown in Fig. 1.

Fig. 2—Position of the induction coil with respect to the pipes during welding

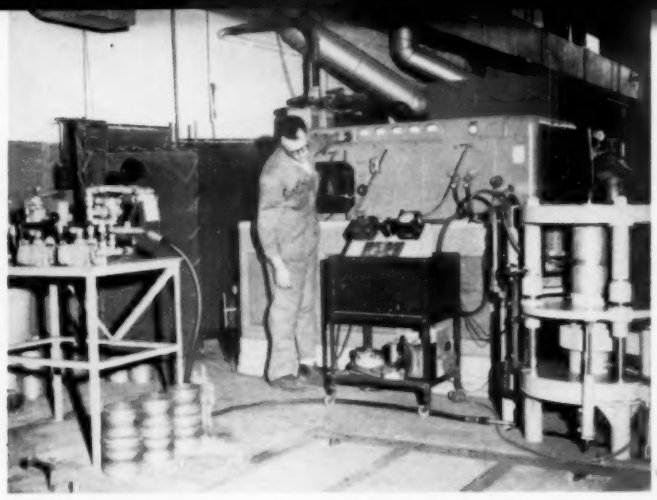


Fig. 3—Over-all view of induction-pressure welding equipment

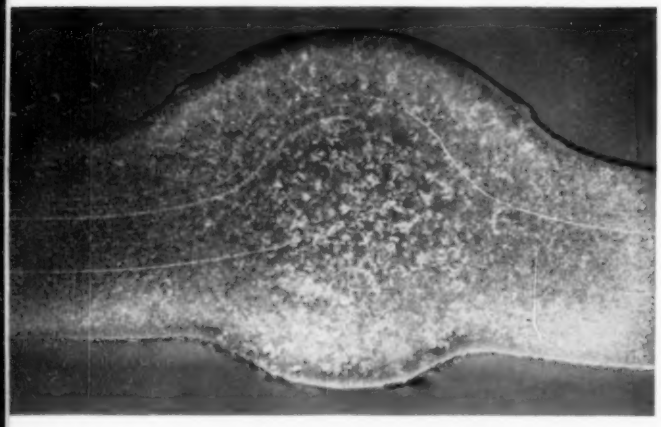


Fig. 4—Typical induction-pressure weld. X7. Note oxygen-rich lamination in pipe material. Hall's Etchant: 20 g $KMnO_4$, 20 g NaOH, 20 g Na_2CO_3, 8 g $K_2Cr_2O_7$ and 200 cc H_2O

Fig. 5—Typical sharp-upset contour weld. X 7. Hall's Etchant: 20 g $KMnO_4$, 20 g NaOH, 20 g Na_2CO_3, 8 g $K_2Cr_2O_7$ and 200 cc H_2O

The pipes were held on a common centerline in the press by two 3-jaw lathe chucks. The press was designed to hold the parts rigid during welding and was equipped with mechanical stops for limiting the amount of upset, if desired.

An induction coil was mounted on the press to be concentric with the pipe with its midplane at the interface between the pipes being welded. Figure 2 shows the position of the coil with respect to the pipes during welding. High-frequency electric current for the induction coil was supplied by an 80-kw, 9600-cps motor-generator-type induction unit. An over-all view of the equipment is shown in Fig. 3.

Because induction heating depends on the magnetic and electrical characteristics of the pipe as well as the magnitude of the current flowing through the coil, the capacitance of the machine had to be adjusted during welding to maintain uniform power input. An automatic timer was used to control the time at which the change in capacitance was made. A contactor also was built into the timer to stop heating when the desired upset distance had been obtained. In addition, the timer measured the total heating time. Reproducible heating cycles and welding conditions were obtained with the automatic timer.

Testing Procedures

The welds were evaluated on the basis of API specifications for manual-welded pipe.* This specification requires guided-bend and tensile tests. Bend specimens (4 root and 4 face) $1^1/_2$-in. wide and 6-in. long were cut from each weld. The upsets were ground off the bend specimens and they were bent around a die that had a radius three times as large as the wall thickness of the pipe (3T bend radius). An open defect greater than $^1/_8$ in. in any direction was considered a failure, except at the edges of the specimens in which case openings greater than $^1/_4$ in. were considered failures. In initial studies, four tensile specimens, one from each quadrant, were oxygen cut from each weld. However, practically all of the welds had satisfactory tensile

*Standard for Field Welding of Pipe Lines, American Petroleum Standard 1104, 4th Ed. (May 1956).

properties so that, for subsequent studies, tensile specimens were usually omitted.

Metallographic examinations also were made to determine the quality of the welds. The main objective of these examinations was to see whether the joint interface could be detected and to correlate the findings with bend and tensile properties of the welds.

Results

The following variables were expected to affect weld quality:

1. Frequency of the induction unit.
2. Geometry of the induction coil.
3. Upset pressure.
4. Upset distance.
5. Heating cycle.
6. Inert-gas shielding.
7. Joint design.
8. Joint alignment.

Initial welding tests showed that satisfactory weld quality could be obtained with a 9600-cps induction unit. This unit was used for practically all of the welding studies.

Several induction-coil designs were investigated briefly. Single-turn coils were machined from copper plate and varied in height from 1/2 to 7/8 in. The distance between the ID of the coil to the OD of the pipe appeared to have considerable effect on the heating characteristics of the coil. Distances of 3/8 to 1/2 in. were tried in welding tests. Although several induction coils could be used to obtain good joints, the use of an induction coil 7/8 in. high with a "coil-to-pipe" distance of 7/16 in. was found to produce the best weld consistency.

Table 1—Welding Conditions Used to Evaluate Round- and Sharp-upset Welds[a]

Welding variables	Sharp-upset contour welds	Round-upset contour welds
Joint design	Square-butt closed joint	Square-butt closed joint
Upset pressure, psi	2150	2450
Average heating cycle, sec	43.4	62.5
Upset during heating cycle, in.	1/16	1/8
Total upset, in.	5/32	3/16 to 7/32

[a] The inside of the pipe was purged with argon before and during welding in these tests.

Effects of Upset Pressure, Upset Distance and Heating Cycle on Weld Quality

The major variables investigated in welding studies were: (1) upset pressure, (2) upset distance and (3) heating cycle.

Upset pressure is the pressure applied at the weld joint during welding. Upset pressures ranging from 1500 to 4000 psi on the pipe wall were studied in the program. The upset pressure was applied before heating was started and was maintained constant throughout the upsetting operation.

The *upset distance* was selected prior to welding and was the distance traveled during the heating cycle. Upsetting that occurred after the heating cycle was not controlled.

The *heating cycle* is the time during which heat is supplied to the joint. By adjusting the power input, short or long heating cycles could be obtained. For example, short heating cycles were obtained when using high power inputs because the joint was heated fast and upsetting was completed sooner than when low power inputs were used. The effects of upset pressure, upset distance and heating cycle on weld quality were studied using the 9600-cycle induction unit, the hydraulic press and the induction coil described previously.

Welding studies showed that differently shaped upset contours could be obtained by changing the upset pressure and/or the power input. Round upset contours (Fig. 4) were obtained with high-upset pressures (2300 to 4000 psi) and a low-power input, and sharp-upset contours (Fig. 5) with low

Table 2.—Results of Bend and Tensile Tests on Sharp- and Round-upset Contour Welds

Number	Number of bend tests made		Number of tensile tests made	Number of Joint failures				
				Guided bend[a]		Vise bend		
	Root	Face		Root	Face	Root	Face	Tensile
Sharp-upset contour welds								
128	8	0	4	0	0	0	0	0
132	8	0	4	0	0	0	0	0
139	4	4	4	0	0	0	4[b]	0
140	4	4	4	0	0	0	0	0
141	4	4	0	0	0	0	4[b]	0
Total	28	12	16	0	0	0	8	0
Round-upset contour welds								
147	4	4	1	0	0	2	0	0
148	4	4	1	0	0	0	1	0
150	4	4	1	0	0	0	0	0
151	4	4	1	0	0	1	0	0
152	4	4	1	0	0	1	0	0
Total	20	20	5	0	0	4	1	0

[a] A 3T bend radius die was used in guided-bend tests.
[b] Fractures consisted of lamination openings.

pressure (1500 to 2300 psi) and a high-power input.

A series of welds was made to determine which type of upset (sharp or round) was best. Welding conditions used in these studies are shown in Table 1.

In general, melting occurred at the outside upset of all sharp-upset contour welds and a considerable number of voids (Fig. 5) were observed at the face of these welds. These voids were caused by laminations in the pipe wall, which ruptured during welding because of overheating. The joint was overheated in this area because of the high power inputs used in making sharp-contour welds. However, the original interface of these welds could not be detected.

Fig. 6—Typical face-bend fracture in sharp-contour weld due to pipe laminations. Hall's Etchant: 20 g $KMnO_4$, 20 g NaOH, 20 g Na_2CO_3, 8 g $K_2Cr_2O_7$ and 200 cc H_2O. Note that the location of the original weld interface can be detected only by the termination of the pipe-wall laminations. X7

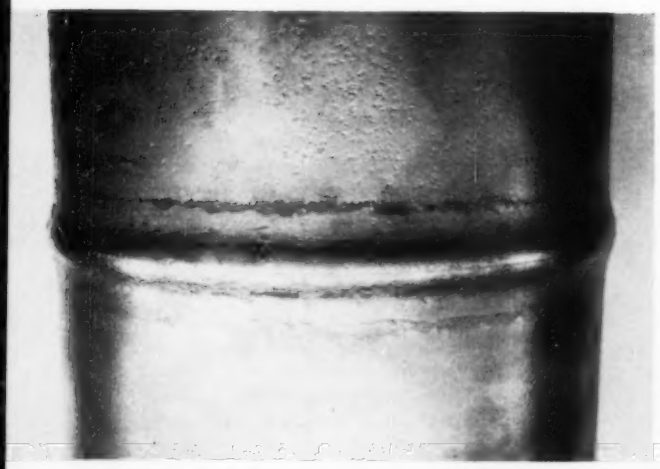


Fig. 7—An induction-pressure weld showing the face of the joint

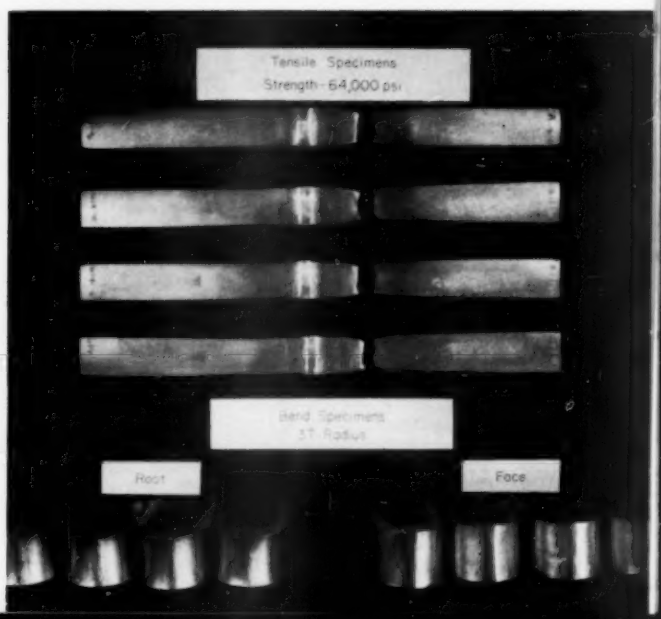
The round-upset contour welds showed no detrimental effects at the outside of the pipe. In some welds, an oxygen-rich bond line could be detected for short distances at the face and root of the welds (Fig. 4).

Results of bend and tensile tests made on this series of welds are shown in Table 2. All of the welds passed API specifications for bend and tensile tests. In an effort to obtain a comparison between round- and sharp-upset contour welds, the bend specimens were bent in a vise after they had passed the 3T bend. In "vise-bend" tests, the ductility of root and face-bend specimens from round-upset contour welds was good (Table 2). The ductility of root bends made on the sharp-upset contour welds also was good. However, partial fractures occurred in making vise-bend tests on the face of sharp-upset contour welds. These failures were caused by laminations in the pipe (Fig. 6) which were opened up by the high temperatures reached in this type of weld. Face vise-bend tests made on sharp-upset contour welds with upsets intact, however, did not fail.

These test results showed that round- and sharp-upset contour welds had good quality. However, it was believed that the voids caused by laminations in all sharp-upset contour welds would be detrimental.

Two methods were used in an attempt to eliminate the voids at the outside of sharp-contour welds. These were: (1) decrease the power input to eliminate overheating at the outside of the pipe and (2) shield the outside of the pipe during welding with a welding flux. The first of these methods failed because it was found that sharp-upset contour welds could not be obtained with low-power inputs. Apparently, a steep temperature gradient is needed to obtain sharp-upset contour welds, and the use of low-power input allows time for the heat to conduct away from the joint and minimize the temperature gradient.

Fig. 8—Typical bend and tensile tests made on an induction-pressure weld that passed API specifications



The use of a welding flux placed in the space between the induction coil and the pipe did not reduce the number of voids in the outside upset. Because these defects, resulting from laminations in the pipe, could not be eliminated from sharp-upset contour welds, work was concentrated on developing optimum welding conditions for round-upset contour welds. Figure 7 shows an outside view of a typical round-upset contour weld.

Table 3 shows typical welding data and results of bend tests, respectively, for welds made to determine satisfactory welding conditions for round-upset contour welds. The square-butt closed-joint design was used in making these welds. As shown in Table 3, good joint quality was obtained with upset pressures of 2450 to 2900 psi, power inputs of 85 and 90% of full power available, and 1/8 to 3/16-in. upset distances. Figure 8 shows typical results of bend and tensile tests made on welds that passed API specifications.

Effect of Shielding on Weld Quality

Studies were made to determine the effect of argon shielding on induction-pressure welds. This information was obtained from welds made using the square-butt closed-joint design with the same range of welding conditions with, and without, argon shielding. In the shielded joints, the argon was applied from the inside. Table 4 shows welding conditions and the results of bend tests made on these welds.

Five of the eight welds made without argon shielding failed to pass API specifications. All but one of

Table 3—Results of Bend Tests Made to Determine Optimum Welding Conditions

Weld number	Upset distance, in.	Power input,[a] %	Total heating cycle, sec	Upset pressure, psi	Remarks	Number of guided-bend tests made[b] Root	Face	Number of Joint failures Root	Face
187	1/8	100	42.3	2900	No melting	4	4	0	0
189	1/8	100	42.9	2750	No melting	4	4	0	0
191	1/8	100	43.6	2600	Slight melting	4	4	0	2
193	1/16	100	44.9	2450	Slight melting	4	4	0	0
198	1/16	100	37.0	2900	No melting	4	4	0	0
199	1/16	100	37.6	2750	No melting	4	4	0	0
200	1/16	100	38.5	2600	No melting	4	4	2	0
205	1/8	90	49.4	2900	No melting	4	4	0	0
206	1/8	90	48.0	2750	No melting	4	4	0	0
204	1/16	90	50.5	2600	No melting	4	4	0	1
203	1/16	90	53.5	2450	No melting	4	4	0	1
210	3/16	85	54.1	2750	Slight melting	2	2	0	0
209	1/8	85	55.3	2600	No melting	4	4	0	0
208	1/8	85	56.3	2450	Slight melting	4	4	0	0

[a] Power is given as a percent of full power available and is merely a machine setting.
[b] A 3T-bend-radius die was used in guided-bend tests.

Table 4—Results of Bend Tests on Welds Made With and Without Shielding

Weld number	Total heating cycle, sec	Upset distance, in.	Upset pressure, psi	Number of guided-bend tests made Root	Face	Number of joint failures Root	Face
Welds made without shielding							
56	50.3	1/8	2500	4	4	0	0
58	51.2	1/8	2500	4	4	0	0
153	63.4	1/8	2450	4	4	4	0
154	63.0	1/8	2450	4	4	4	0
155	66.0	1/8	2450	4	4	4	0
156	64.1	1/8	2450	4	4	3	0
14	56.4	1/8	2750	2	2	0	0
15	58.1	1/8	2750	2	2	2	2
Welds made with shielding							
55	49.8	1/8	2550	4	4	0	0
57	52.6	1/8	2500	4	4	0	0
148	57.7	1/8	2450	4	4	0	0
150	56.2	1/8	2450	4	4	0	0
151	65.2	1/8	2450	4	4	0	0
152	63.4	1/8	2450	4	4	0	0
12	56.9	1/8	2750	2	2	0	1[a]
13	56.5	1/8	2750	2	2	0	0

[a] Fracture occurred at the edge of the specimen at the weld interface.

the eight welds made with argon shielding passed API specifications. Only one bend failure was encountered in testing the shielded welds and this failure initiated at the edge of the specimen along the weld interface. The validity of bend tests where failures occur at the edge of the specimen is questionable.

Effect of Joint Design and Joint Alignment on Weld Quality

Although it had been found that good-quality joints could be made with the square-butt closed joint, several welds were made to study other joint designs. The other joint designs were:

1. A double-vee joint with a $^1/_8$-in. land and an included angle of 90 deg.
2. A single-vee joint with an included angle of 8 deg.
3. Square-butt joint with a $^1/_8$-in. separation between the pipes during heating.

The bend properties of welds made with these joint designs were poor. On the basis of this study, a square-butt closed-joint design would be recommended for welding pipe with this process.

In addition, a brief study was made in an effort to determine whether good-quality welds could be obtained in welds made: (1) with a joint gap in some areas around the circumference and (2) with out-of-round pipe resulting in joint misalignment. In making these tests, the square-butt closed joint was used. Results of bend tests made on these welds are shown in Table 5. Welds made with maximum joint gaps of 0.030 and 0.018 in. passed the 3T guided-bend tests. These results indicate that the process can tolerate some joint separation. In addition, these results indicate that some amount of joint misalignment can be tolerated. The weld made with a joint misalignment of $^1/_{32}$ in. passed the guided-bend tests, whereas the weld made with a joint misalignment of $^1/_{16}$ to $^3/_{32}$ in. did not.

Discussion and Recommended Procedures

On the basis of this study, the induction-pressure-welding process is considered capable of producing girth joints which meet strength and integrity requirements of underground pipe lines. The following conditions were found to be satisfactory for welding $6^5/_8$-inch OD pipe:

1. Upset pressure—2450 to 2900 psi.
2. Upset distance traveled during the heating cycle—$^1/_8$ in.
3. Heating cycle—50 to 65 sec.
4. Shielding—argon purged inside pipe at 50 cfh.
5. Joint design—square-butt closed joint free from dirt, oxide, and grease.

With these conditions and good joint alignment, welds were produced with bend and tensile properties that passed API specifications for manual-welded pipe. In most of these welds, the joint interface could be detected for short distances at the face and the root of the weld in metallographic examinations. However, it is believed that the appearance of the interface for short distances is not detrimental because some welds made without argon shielding had satisfactory bend properties even when the interface could be detected completely across the weld.

An indication of the consistency of induction-pressure welds made in pipe can be seen in Table 6. Thirty-six welds were made during this study with welding conditions that fell in the recommended range listed previously. Of the 36 welds, 34 joints met the API bend requirements and two joints each had one bend failure. One failure (Weld No. 212) was at the edge of the bend specimen and the validity of the test is questionable because an adjacent specimen did not fail. The other fracture (Weld No. 47) occurred in the first weld made using these welding conditions. An adjacent specimen in this weld also did not fail.

Table 5—The Effects of Joint Alignment on Weld-bend Ductility

Weld number	Maximum joint separation, in.	Joint misalignment, in.	Number of guided-bend tests made[a]		Number of joint failures	
			Root	Face	Root	Face
157	0.030	...	3	3	0	0
158	0.018	...	3	3	0	0
216	...	$^1/_{32}$	2	2	0	0
217	...	$^1/_{16}$–$^3/_{32}$	2	2	2	0

[a] A 3T-bend-radius die was used in the guided-bend tests.

Conclusions

Welding studies were made with the induction-pressure welding process on standard $6^5/_8$-in. OD pipe. It was found that satisfactory welds, which had bend ductility and tensile strengths in excess of those specified by API for field-welded joints, could be made consistently with proper welding conditions, argon shielding and a square-butt closed-joint design with good joint alignment. Welds made with some intentional amounts of misalignment, out of roundness, and joint gap also met the API specifications for manual-welded pipe, but it is believed that these welds were of lower quality than welds made with good alignment.

On the basis of this study, the induction-pressure-welding process is considered satisfactory for producing girth joints which are more than adequate, by present standards, for petroleum pipe-line fabrication. It is readily adaptable to in-plant or yard joining operations and, with adequate engineering design, could be used on a pipe-line spread under actual field conditions. Because the size of equipment required to make a weld increases with pipe diameter, a practical limit for field-welding applications would probably be about 20 in. in diam. The prime requirement for obtaining good-quality pressure welds in the field would be to have suitable equipment for applying pressure and aligning the

Table 6—Welds Made Under Recommended Welding Conditions

Weld number	Total heating cycle, sec	Upset distance, in.	Upset pressure, psi	Argon shielding, cfh	Number of guided-bend tests made		Number of joint failures	
					Root	Face	Root	Face
47	51.5	1/8	2500	50	4	4	1	0
48	48.9	1/8	2550	50	4	4	0	0
49	50.6	1/8	2550	50	4	4	0	0
50	63.0	1/8	2550	50	4	4	0	0
51	61.0	1/8	2550	50	4	4	0	0
52	51.4	1/8	2550	50	4	4	0	0
53	52.0	1/8	2550	50	4	4	0	0
54	49.0	1/8	2550	50	4	4	0	0
55	49.8	1/8	2550	50	4	4	0	0
57	52.6	1/8	2500	50	4	4	0	0
145	64.1	1/8	2450	50	4	4	0	0
146	57.4	1/8	2650	50	4	4	0	0
147	54.9	1/8	2650	50	4	4	0	0
148	57.7	1/8	2450	50	4	4	0	0
150	56.2	1/8	2450	50	4	4	0	0
151	65.2	1/8	2450	50	4	4	0	0
152	63.4	1/8	2450	50	4	4	0	0
157	57.3	1/8	2450	50	4	4	0	0
158	56.6	1/8	2450	50	4	4	0	0
205	49.4	1/8	2900	50	4	4	0	0
206	48.0	1/8	2750	50	4	4	0	0
207	49.6	1/8	2600	50	4	4	0	0
208	56.3	1/8	2450	50	4	4	0	0
209	55.3	1/8	2600	50	4	4	0	0
212	56.9	1/8	2750	50	2	2	0	1[a]
213	56.5	1/8	2750	50	2	2	0	0
218	55.8	1/8	2450	50	1	1	0	0
219	54.2	1/8	2450	50	1	1	0	0
220	59.2	1/8	2600	50	1	1	0	0
221	55.7	1/8	2600	50	1	1	0	0
222	54.9	1/8	2600	50	1	1	0	0
223	54.2	1/8	2750	50	1	1	0	0
224	53.3	1/8	2750	50	1	1	0	0
225	55.2	1/8	2750	50	1	1	0	0
226	56.0	1/8	2900	50	1	1	0	0
227	54.9	1/8	2900	50	1	1	0	0

[a] Fracture occurred at the edge of the specimen at the weld interface.

pipe. The equipment would have to be designed to: (1) join 40 to 80-ft lengths of pipe, (2) align the joints so that a minimum of mismatch is obtained and (3) be rigid enough to maintain line-up as the pressure is applied. In addition, the ends of the pipe should be sized to minimize mismatch. An expanding mandrel could be used to expand the ends of all pipe to the maximum allowed under API specifications to obtain this sizing. Also, a cutoff wheel, saw or grinding wheel would have to be attached to the clamp to prepare clean square-butt joints that would abut with a minimum of joint separation. With equipment meeting these requirements and a high-frequency (2000 to 10,000 cycles) 250-kw induction unit, it is expected that girth welds could be made at the rates required for pipe-line fabrication with the quality and consistency in the laboratory.

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An arrangement of jigs for assembling and welding plate girders. Control of camber and alignment of parts at the outset is demonstrated

Types and Causes of **Distortion** in Welded Steel and Corrective Measures

are assessed, and practical solutions based upon analytical studies, as well as upon the experiences of structural fabricating shops and erectors, are suggested

BY OMER W. BLODGETT

Shrinkage of weld metal and accompanying distortion in structural fabrication may or may not be a serious problem. When it is not, the matter is ignored; when it is, many ideas and theories usually are advanced as possible explanations and solutions. Often these ideas are in conflict. What follows herein is an attempt to assess the causes of structural distortion, to see what variables affect it, and to suggest practical solutions based upon this analysis and upon the experiences of structural fabricating shops and erectors.

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Paper presented at AWS 1959 National Fall Meeting held in Detroit, Mich., Sept. 28–Oct. 1, 1959.

Analysis of distortion is complicated by a number of factors. First of all, it is a heat problem and the conduction and flow of heat are complex.

Second, the physical properties of steel vary with increasing temperature. Yield point decreases, modulus of elasticity decreases, coefficient of thermal expansion increases, thermal conductivity decreases and specific heat increases.

Third, conditions of restraint are variable. Restraint from external clamping and internal restraint due to the mass and stiffness of steel plate exert important influences.

Time is a fourth factor, since it leads to rapidly changing conditions.

And finally, different welding procedures—type

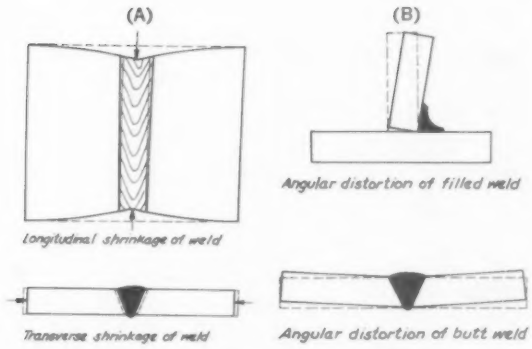

Fig. 1—Exaggerated representations of longitudinal weld shrinkage, transverse shrinkage and angular distortion

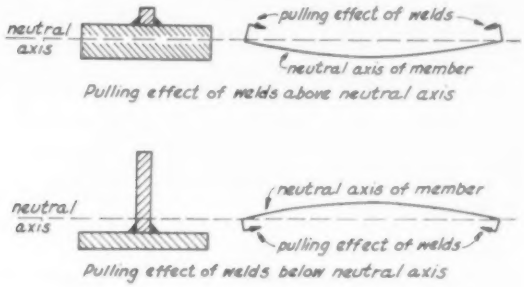
neutral axis
pulling effect of welds
neutral axis of member
Pulling effect of welds above neutral axis
neutral axis
neutral axis of member
pulling effect of welds
Pulling effect of welds below neutral axis

Fig. 2—Bowing and cambering caused by longitudinal shrinkage not acting along the neutral axis of the member

and size of electrode, welding current, speed of travel, joint design, preheat and cooling rates—all bear significantly on the question.

Types of Distortion

When distortion is encountered, it may be revealed by longitudinal or transverse shrinkage of the weld, as illustrated in Fig. 1, part A. If transverse shrinkage is not uniform throughout the thickness of the weld, angular distortion will result, as shown in Fig. 1, part B. If longitudinal shrinkage does not act along the neutral axis of the member, it will cause bowing or cambering as indicated in Fig. 2.

Basic Causes

Distortion derives from the combined effects of the following:

1. Welds cool and shrink, along with a portion of the base metal adjacent to them. This represents a shrinkage force (F).

2. The neutral axis of the section of the member is an imaginary line or backbone about which the welds shrink and tend to pull the member. Distance between the center of gravity of the welds and the neutral axis of the member represents the moment arm (d).

3. Resistance of the member against this shrinkage is indicated by the moment of inertia of the section (I). This represents the resistance to distortion and also the resistance against straightening.

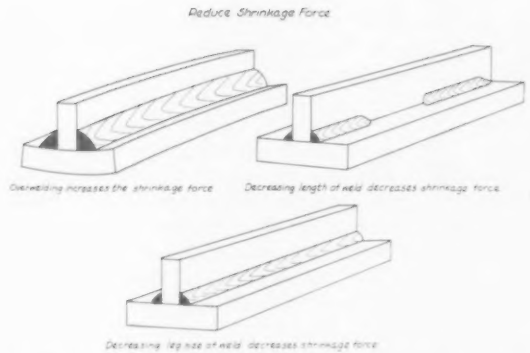
Reduce Shrinkage Force
Overwelding increases the shrinkage force
Decreasing length of weld decreases shrinkage force
Decreasing leg size of weld decreases shrinkage force

Fig. 3—Use of intermittent weld beads or decreased leg size reduces shrinkage forces causing distortion in instances of overwelding

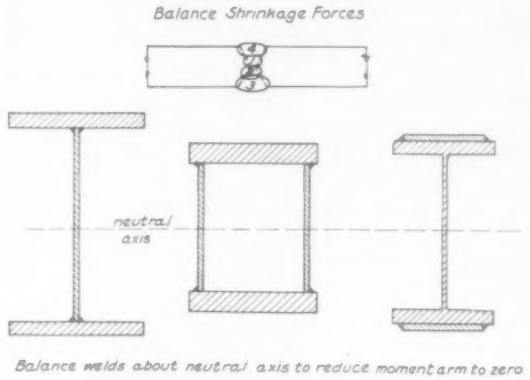

Fig. 4—Balancing shrinkage forces about the neutral axis of the weldment reduces moment to zero because moment arm is zero

Overwelding increases the shrinkage force and increases the tendency to distort. Any means to reduce the amount of welding, either by decreasing the leg size or the length, by using intermittent welds, will relieve this condition. Figure 3 is a graphic illustration of these techniques.

Weld shrinkage should be put into use in pulling the member or connection into proper alignment; in other words, preset the joint, or prebend the member.

Welding should be balanced about the neutral axis of the member. This will make the moment arm (d) equal to zero. Although there is always some shrinkage force (F) resulting from the shrinking welds, the moment (M) is equal to zero because it is equivalent to the product of the shrinkage force and moment arm; in this case, the latter is zero. Examples are shown in Fig. 4.

Grooved-tee welds or fillet welds made with the submerged-arc automatic process, having deep penetration, will have a center of gravity deeper into the plate. If the neutral axis of the member is below

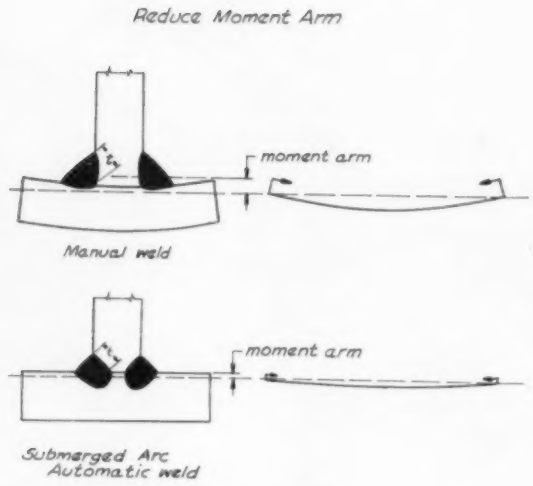

Fig. 5—Moment arm may be reduced through increased penetration

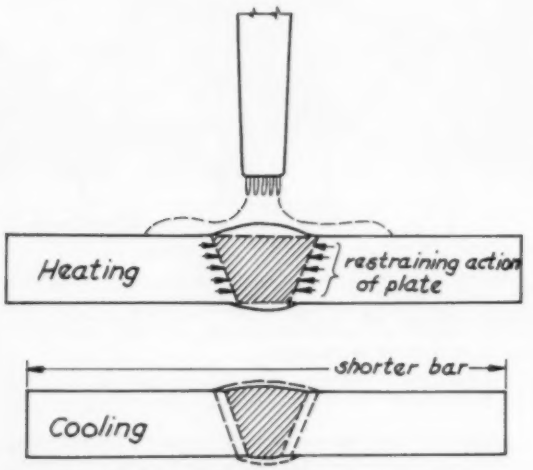

Fig. 6—Heat effect of welding causes metal adjacent to weld to expand but it is restrained by cooler sections

the center of gravity of the welds, this will decrease the distance between welds and neutral axis, thus greatly reducing any distortion (Fig. 5).

Shrinkage of weld metal alone is not sufficient to account for the amount of shrinkage actually encountered. Unit shrinkage must be applied to a width greater than the weld alone thus including some of the plate adjacent to the weld. Figure 6 shows this graphically. Heat of welding causes the metal adjacent to the weld metal to expand. However, this metal is restrained by the relatively cooler sections of the rest of the plate. Almost all of the volume expansion takes place in thickness. Upon cooling, the heated section undergoes volume contraction and this means that shrinkage stresses will be applied in transverse and longitudinal directions. Result is that this adjacent base metal tends to

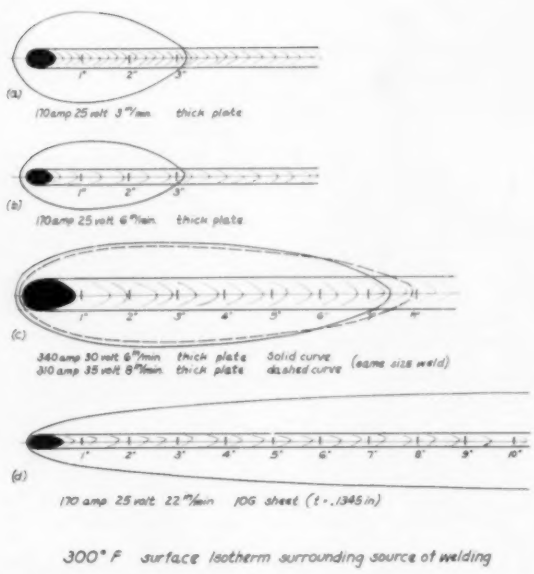
(a)
170 amp 25 volt 3"/min. thick plate
(b)
170 amp 25 volt 6"/min. thick plate
(c)
340 amp 30 volt 6"/min. thick plate Solid curve
310 amp 35 volt 8"/min. thick plate dashed curve (same size weld)
(d)
170 amp 25 volt 22"/min 10G sheet (t = .1345 in)
300° F surface isotherm surrounding source of welding

Fig. 7—Surface 300° F isotherm surrounding the source of welding for four different procedures. All are single-pass welds

shrink along with the weld metal. If a piece of steel is fully restrained from expanding longitudinally, it can be shown that an increase of about 200° F will cause it to be stressed above its yield point.

Any welding procedure which decreases the amount of base metal adjacent to the weld which shrinks will also decrease distortion; hence, faster speeds of welding, the use of iron-powder type manual electrodes, semiautomatic and fully automatic submerged-arc welding, and finally the vapor-shielded automatic welding method, should progressively decrease distortion.

For this reason, it is of interest to study the 300° F isotherm of a weld made under different procedures and plate thicknesses (see Fig. 7). Any procedure resulting in a narrow 300° F isotherm would, of course, be preferred. The four procedures are self-explanatory. They represent the result of a single-pass weld and do not indicate what happens with several passes. It is believed, for lack of better information other than experience, that the contraction or distortion resulting from each pass combines or accumulates to form the final over-all distortion. This helps to explain, for example, why a vertical weld made by weaving in the up direction usually results in less distortion than the same weld made with stringer beads in the horizontal position.

Transverse Contraction

Transverse shrinkage may be of no importance in welding a lifting lug to a structure, but it would be a factor to be controlled in the welding of a beam to a column, expecially in a series of beam connections where the transverse shrinkage could add up to a sizable amount along the entire length of a building.

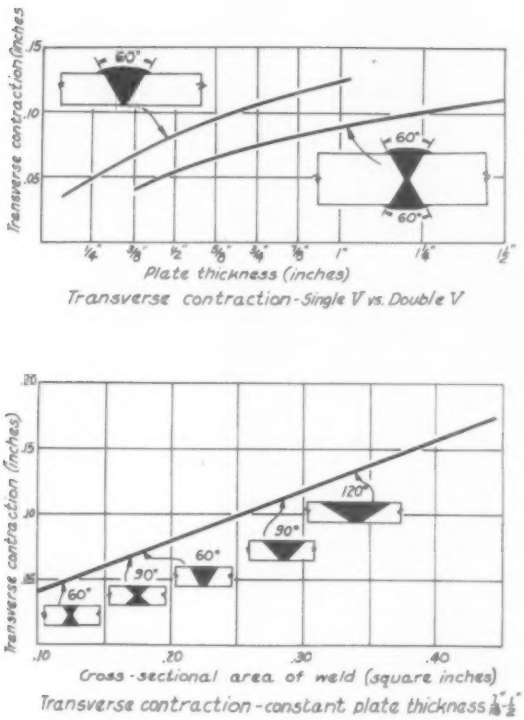

Fig. 8—Transverse contraction for plate of varying thickness (above) and for constant thickness with varying weld area (below)

The charts in Fig. 8 throw some light on transverse contraction. The lower chart shows that, for a given thickness of plate, transverse shrinkage varies almost directly with the cross-sectional area of the weld. The obviously over-large included angles are just to illustrate the relationship and are not representative of accepted practice. The top chart compares the effects of single and double-vee joints. Both charts assume no unusual restraint of the plates against transverse shrinkage. Calculations show that transverse shrinkage is about 10% of the average width of the cross section of the weld area. With welds made by submerged arc, the cross section of the fused portion of the joint must be used, instead of just the area representing weld metal added.

When shrinkage becomes a problem in the field welding of beams to columns, the erector usually spreads the joint open by the amount he expects it to contract after welding. After the beam is welded in place, the distance between the columns is again measured to check this movement, and the spreading open of the next joint is governed accordingly.

Angular Distortion

In Fig. 9 are shown eight different flanges, fillet welded as indicated, with actual and calculated warpages for each. Formula for calculating warpage is reproduced at the top. Close agreement between the two values is obvious. Only three exceed the AWS allowable limit (1% of the width of the flange) as set forth in *Standard Specifications for Welding Highway and Railway Bridges (1956)*. They are naturally overwelded.

Bending of Longitudinal Members

The combined shrinkage force of the weld area plus some adjacent base metal produces a shortening

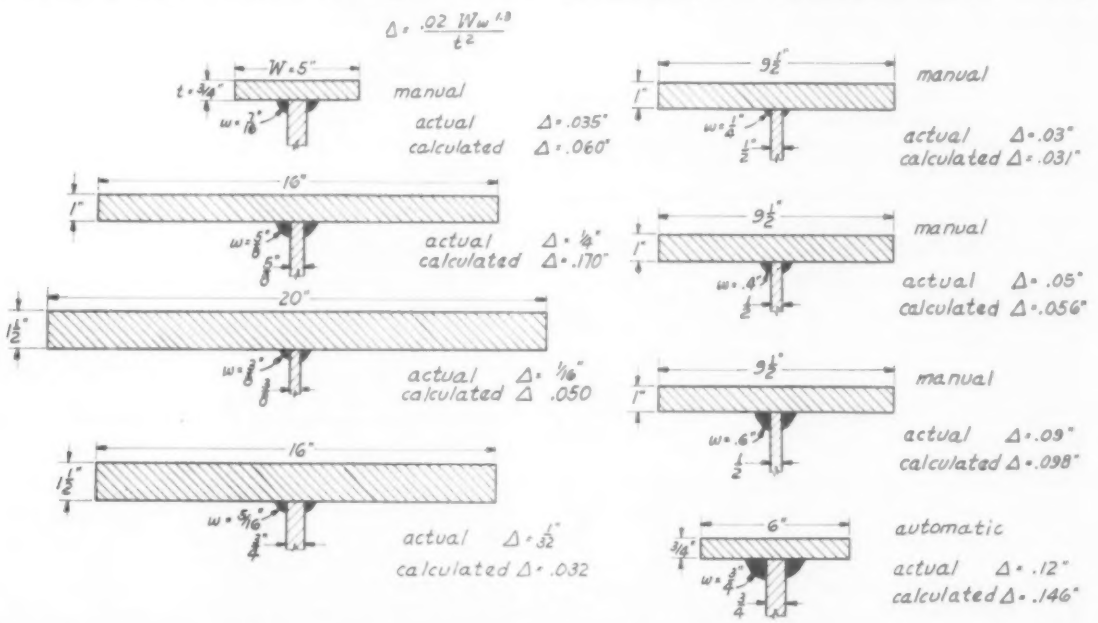

Fig. 9—Eight different welded-flange sections with the actual and calculated warpages. At top is formula for calculated values

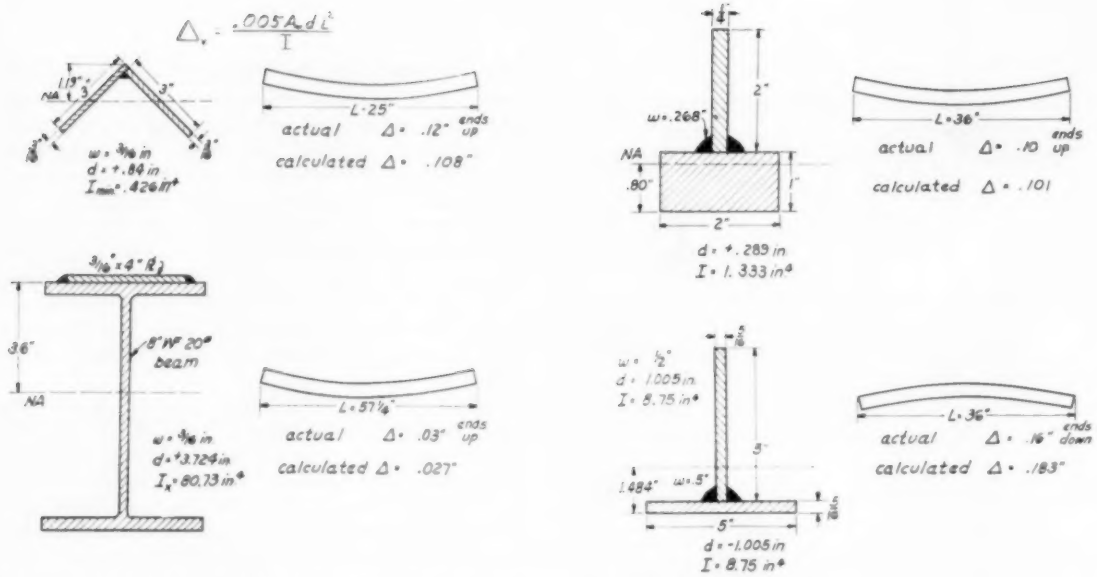
actual Δ = .12" ends up
calculated Δ = .108"
actual Δ = .10 ends up
calculated Δ = .101
8" WF 20# beam
actual Δ = .03" ends up
calculated Δ = .027"
actual Δ = .16" ends down
calculated Δ = .183"

Fig. 10—Calculated distortion in bending of longitudinal members was close to actual bending values

of the member.

If the center of gravity of this welding-shrinkage force does not coincide with the neutral axis of the member, a shrinkage moment will be produced—shrinkage force multiplied by moment arm. This moment will result in distortion or bending of the member, the amount depending upon the magnitude of the moment and the resistance of the member to bend which is governed by its moment of inertia.

Assuming no unusual initial stresses, the following formula (see Fig. 10) will indicate the amount of distortion or bending resulting from any longitudinal welding on a given member:

$$\Delta = 0.005 \frac{A_w d L^2}{I}$$

- A_w = total cross-sectional area within the fusion line of all welds, sq in.
- d = distance between the center of gravity of the weld group and the neutral axis of the member, in.
- L = length of member, assuming welding full length, in.
- I = moment of inertia of member, in.^{4}
- Δ = vertical movement, in.

When long members are symmetrically welded, as in Fig. 11, the first weld and adjacent metal expand longitudinally for a short period of time, and then contract. Normally, if the second weld, at the bottom, is made after the member has cooled from the first weld, there will be a slight bend since the second weld never quite pulls back the same amount as the first.

If rather-high welding speeds are used on this thin member, greater differential in temperature throughout the cross section will develop and this differential may persist for some time. This will cause the top flange to expand lengthwise as in (*a*). After welding, as the heat distributes itself, the member will gradually straighten out (*b*). Finally, at room temperature the member (*c*) will be left with a slight bend due

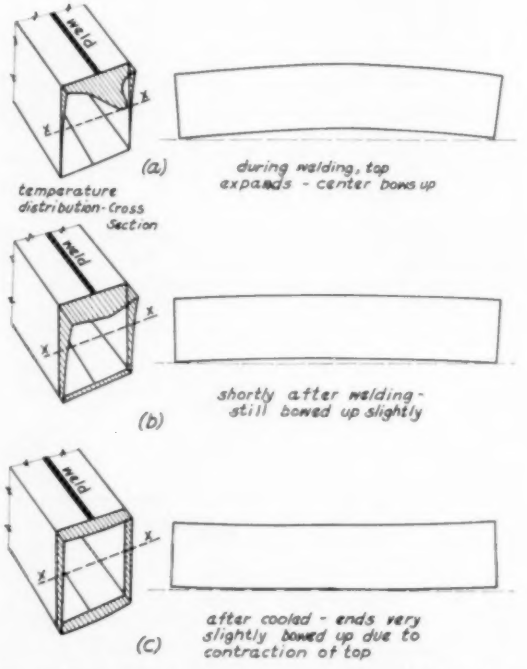

Fig. 11—Box section of thin material and relatively long, with welds top and bottom. Fast turnover before second weld results in straight member

to the contraction of the top weld and adjacent area. If the work piece could be turned over quickly soon after completing the first weld, and if the second weld were started while the workpiece was still bowed, the member would usually come out straight. In effect, this is the same as prebending the member for the second weld.

An example of unsymmetrical welding is the at-

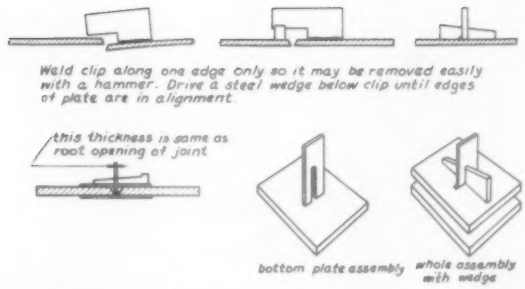
Weld clip along one edge only so it may be removed easily with a hammer. Drive a steel wedge below clip until edges of plate are in alignment
this thickness is same as root opening of joint
bottom plate assembly
whole assembly with wedge

Fig. 12—Methods of applying small clips along one side of light plate to bring edges into alignment for welding

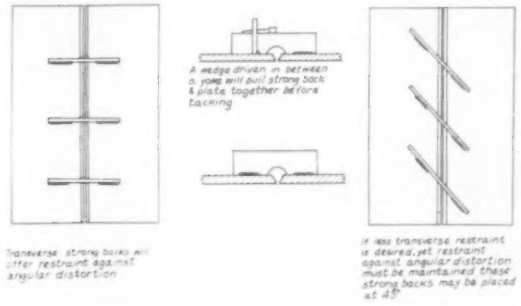
A wedge driven in between a yoke will pull strong back & plate together before tacking
Transverse strong backs will offer restraint against angular distortion
If less transverse restraint is desired, yet restraint against angular distortion must be maintained these strong backs may be placed at 45°

Fig. 13—Several methods of using strongbacks to hold temporarily a butt joint in alignment while welding thin plates

tachment of a cover plate to one flange of a rolled beam. Since all the welding is on one side, the beam ends will tend to rise. The usual solution is to prebend in the opposite direction by an amount the beam would be expected to distort, and then hold parts in this position until after welding. If two similar beams are to have cover plates attached, they may be clamped or welded together at the ends and then spread apart at the center.

Sometimes these rolled beams with one welded cover plate must be cambered. Some fabricators try to estimate the camber resulting from the welded cover plate, tempered by experience, and then order the beam for the final required camber, minus what the welding will produce. Other fabricators order straight beams from the mill, weld the cover plate which gives a slight camber, and then put in the rest of the desired camber by flame shrinking the bottom flange.

Developing Alignment

Various methods are used for pulling plate edges into alignment and holding them during welding. Most joints can be placed into desired alignment by welding a small clip to the edge of one plate and driving a steel wedge in between this clip and the second plate until the edges are lined up. The clips are welded on one side only so they may be easily removed later with a hammer. The arrangement is illustrated in Fig. 12. Short bars serving as strongbacks may be placed at right angles to the joint to maintain alignment, as in Fig. 13. Where less transverse restraint is desired, yet restraint against angular movement must be maintained, the strongbacks may be placed at 45 deg to the joint as shown.

Peening

Since the weld area contracts, peening, if properly applied, tends to expand this area to some extent, but only near the surface. Upsetting or expansion of the metal by peening is most effective at higher temperatures where yield strength of the metal is rather low; yet, on the other hand, most of the distortion problem occurs at the lower temperatures after the yield strength has been restored to its higher value. A disadvantage of peening is that it work hardens the surface of the metal.

Flame Shrinking

Flame straightening or shrinking is a method of localized heating by torch. Heat causes the metal to expand, but it is restrained in all direction by surrounding cooler metal. As a result, this area of metal expands abnormally through its thickness and, upon subsequent cooling, tends to become shorter in all directions, as well as thicker. The part so treated will become shorter with successive applications of heat.

General Summary

For single-pass welds (not necessarily the same size) made with the same welding current, faster arc speeds result in a narrower width of adjacent metal shrinking and, therefore, in less contraction per pass. Slower arc speeds increase the width of adjacent metal and increase the contraction per pass.

For a given-size weld made with the same welding current, a slower arc speed with fewer passes will result in less contraction than a faster arc speed and correspondingly greater number of passes. It is believed that this is so because contraction increases directly with the number of passes, whereas it increases at a slower rate with decreased arc speed.

For the same weld size, a procedure using higher welding currents with corresponding faster speeds will result in less contraction.

If stresses in the order of the yield point result in and near the weld area, as a result of the weld being made under rather restrained conditions offered by the member, it is reasonable to state that material having higher yield strength will result in a higher residual stress under the same conditions. For all practical purposes, the modulus of elasticity, i.e., the property of material which governs its resistance to movement, is the same for all steels. It would seem that a steel having a higher yield strength would promote greater distortion when welded under the same conditions, if indeed distortion should exist at all. This is generally experienced in hard-surfacing applications as compared to mild-steel weldments; also, it is believed that it would be true for low and high-alloy steels, although to a lesser extent.

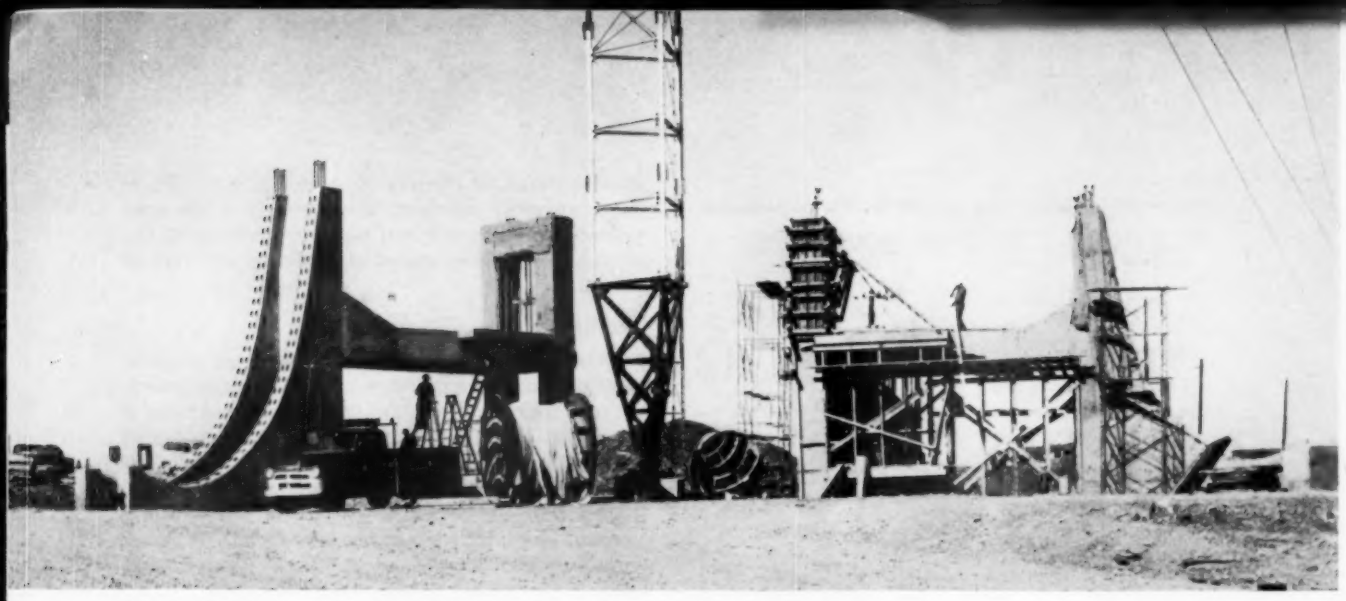

Fig. 1—View of towers for Naval Radio Station at Cutler, Me.

Carbon-Dioxide Welding

of Heavy Sections for Radio Towers

includes the joining of low-alloy plates up to 1-in. thick to solid rounds varying in diameter from 6 to 11 in.

BY G. D. RIES AND J. MYERS

ABSTRACT. This paper describes the application of carbon-dioxide welding to the construction of large radio towers fabricated for the Navy. The unique feature of the operation was the application of the CO_2 process to the welding of heavy low-alloy plates up to 1 in. thick to solid rounds varying in diameter from 6 to 11 in. Also included are other details relating to the construction of the towers. Special attention is given to the procedure that led to the selection of the CO_2 process for welding the 1-in. plates and to the tooling for shop welding. Production experience established that CO_2 welding was an economic, efficient and satisfactory solution to the unique problems encountered in this project.

Introduction

In the past, use of the CO_2 welding process had been limited to deposition of small, single-pass fillets $^5/_{16}$ in. or under in size. This paper describes the unique use of CO_2 welding to deposit heavy fillets up to $^5/_8$ in. in size in the fabrication of 26 towers for the U. S. Navy. The function of the towers is to support the antenna for the world's largest and most powerful radio-transmitting station. The average height of the towers is 900 ft. The station's output power is 2 megawatts at a low frequency. Erection was in two arrays, each containing 13 towers and covering an area of $2^1/_2$ sq. miles (see Fig. 1). This station will provide radio contact with naval vessels operating in the North Atlantic and polar regions.

Tower legs were fabricated from 32-ft long solid rounds varying in diameter from 11 in. for lower sections to 6 in. for topmost sections. A total of 5470 tons of structural steel was required to fabricate the tower legs. Another 1000 tons of plate material varying in thickness from $^5/_8$ to $2^1/_4$ in. were consumed in fabricating the hundreds of attachments welded to the legs. Attachments of about 3000 different sizes and shapes were welded to the round legs using 40,000 lb of CO_2 filler wire and 50,000 lb of metal-arc electrodes.

Technical Provisions

Towers were fabricated in accordance with Navy Specification 22YC for statically loaded structural-steel work. Included in the specification are sections as listed below:

Section 1:
General Requirements
A. Application.
B. Definitions.

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Section 2:
Allowable Unit Stress
A. For base metal.
B. For weld metal.
C. Effective areas of base metal.
D. Effective areas of weld metal.
E. Strength of welds.
Section 3:
Welds and Joints
A. Forms of welds.
B. Fillet.
C. Groove.
D. Positions of welds.
E. Strength of connections.
Section 4:
Loads and Design
A. General loading.
B. Dynamic loading.

In addition to supporting specified loads, the towers were required to resist additional loading equivalent to 3 in. of ice and to withstand stresses which would result from 175 mph winds. These factors entailed design considerations not covered by 22YC. Consequently, the following notable exceptions to Specification 22YC were made in order that the integrity of the tower design would meet the additional stresses imposed by the elements.

Base Metal. Material requirements for tower legs and leg-member splicers were revised to conform to ASTM Specification A242-55 which requires a high-strength low-alloy structural steel with a minimum yield strength of 45,000 psi. Material for other structural members was required to conform to material Specification ASTM A7-56T as outlined in 22YC, requiring a minimum yield strength of 30,000 psi.

Allowable Stress. In the tower fabrication, low-alloy high-strength steel was to be welded with filler wire having a minimum yield strength greater than 55,000 psi (or 10,000 psi higher than the base metal). Because of this, the allowable unit stress on the throat of fillet welds was increased. In 22YC, stresses in welded connections are considered as shear on the throat of fillet welds for any direction of applied stress and the allowable unit stress is 15,000 psi, but for the tower fabrication, the 15,000 psi was increased to 20,000.

Preheat. Preheat is not a requirement of 22YC for welding 30,000-psi yield-strength steel. The use of low-alloy 45,000-psi yield-strength steel, however, required the use of minimum preheat and interpass temperatures. Whenever any part of an alloy member being welded exceeded 1 in. in thickness or diameter, minimum preheat and interpass temperatures of 300° F were required. This temperature was extended from the weld area for a minimum distance of four times the thickest member.

Stress Relieving. Stress relieving of all low-alloy welds was also specified by the designers. However, requirements for stress relieving were rescinded for low-alloy high-strength weldments if the percentage carbon plus $^1/_6$ the percentage manganese did not exceed 0.50% and provided a minimum shop temperature of 60° F was maintained.

During melting of the low-alloy steel, close control of the chemistry of every heat was maintained in order to meet the analysis limitations. Shop temperature during fabrication was maintained above the minimum specified. Consequently, stress relieving did not become a fabrication requirement.

In addition to the exceptions to 22YC, it was also specified by the tower designer that four full-size test specimens of each type of weldment shown on the drawings and of each class of steel were to be prepared. Physical properties of said weldments were not to be less than the minimum physical properties of the steel being used.

Welding Process

The choice of an automatic welding process for fabricating the towers involved a careful analysis. A first impression of the fillet-weld requirements to join the many attachments to the tower legs was that this was a job for submerged-arc welding. The submerged-arc process is fast, capable of meeting production rates, readily lends itself to welding low-alloy steels and deposits one pass fillets with the required throat thickness to withstand design loads.

However, the shop in which this work was scheduled does not normally fabricate heavy weldments. Consequently, submerged-arc equipment purchased for the tower job would not be applicable to future work. Furthermore, it was concluded that the added burden of flux recovery-slag cleaning and the difficulties associated with handling flux would be costly and possibly would slow the welding operation to the point where production schedules could not be met. For these reasons, the CO_2-gas process was considered for tower construction.

Desirable characteristics of the CO_2 process are:

1. It produces high-quality welds.
2. Has high-deposition rates.
3. Has a forceful, deep-penetrating arc.
4. The arc is visible.
5. No slag cleaning is necessary.

Undesirable characteristics are:

1. Weld puddle lacks fluidity and, therefore, produces a high convex bead.
2. Weld puddle has high surface tension producing a narrow bead.
3. Arc atmosphere is oxidizing, resulting in a loss of alloying elements.
4. Cannot be used in drafty or windy areas.

The fourth undesirable characteristic of the CO_2 process presented no problem. Production welds would be made in a shop free of drafts. The other undesirable characteristics presented two obstacles to the use of CO_2 welding in tower fabrication.

1. To avoid the narrow, high convex bead it was necessary to increase the fluidity of the weld puddle and to counteract the high surface tension.

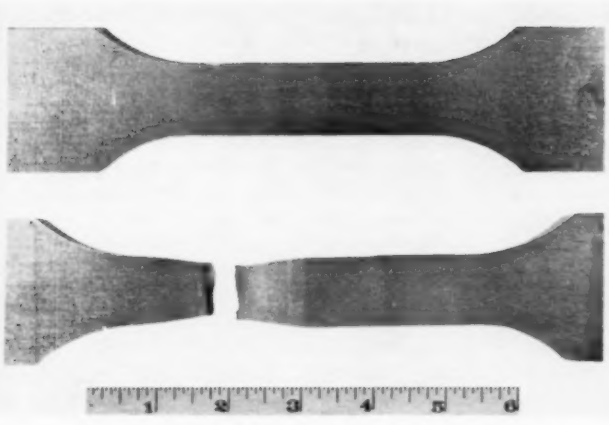

Fig. 2—Tensile-test bars sectioned from a procedure-qualification test plate. Note that failure of the broken bar occurred in the base metal

Fig. 3—Side-bend-test specimens showing the high degree of ductility across the weld

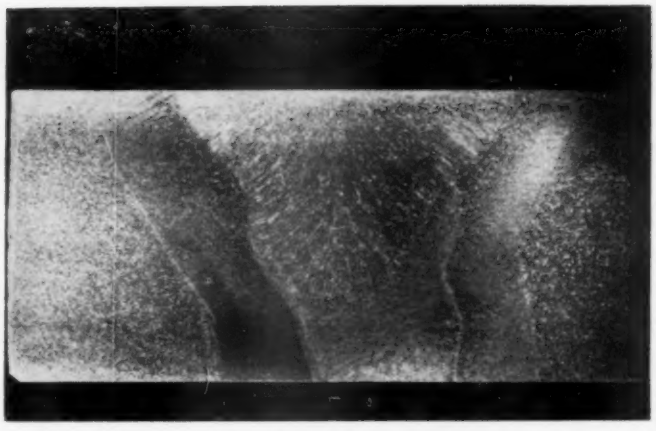

Fig. 4—A photomacrograph of the multi-pass procedure-qualification test plate. This illustrates good fusion and absence of porosity in multipass welds

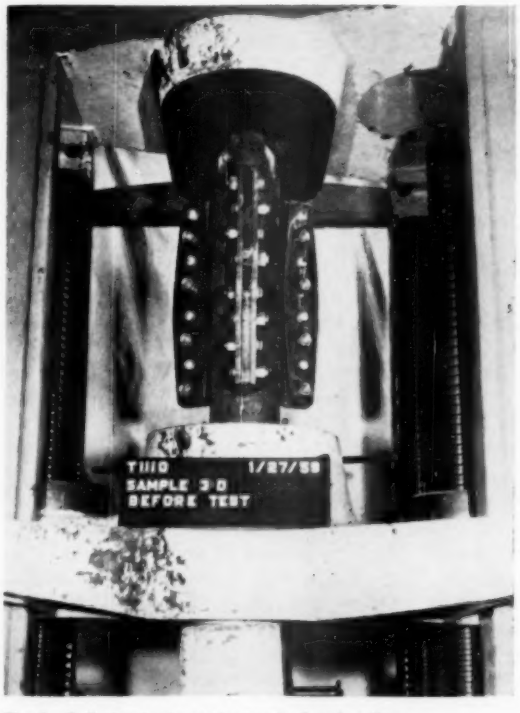

Fig. 5—Full-size test specimens before loading

2. Filler wires had to be carefully selected to minimize oxidation of alloys in the deposit and thereby obtain the specified weld strength.

Initial attempts to overcome the lack of fluidity and high surface tension were confined to manipulation of the welding variables. During these tests, many different combinations of common welding variables were used, but none of them were successful in producing the desired results. Finally, other techniques were investigated. The electrodes were tilted at various angles, puddle size was varied and ultimately a favorable combination was found. The right combination was to tilt the electrode 15 deg in the direction of travel and to reduce the welding speeds. Reduced welding speeds permitted the maintenance cf a large fluid weld puddle. Fluidity was increased by the superheat resulting from the greater heat input at the lower welding speeds. Angling the electrode counteracted the high surface tension by directing the arc force where it would be most effective. The arc force directed at the weld puddle spread the molten metal out to the side walls. By the combination of these conditions—angle of electrode, large superheated puddle—lack of fluidity

Table 1—As-welded All-weld-metal Tensile Properties of Four CO_2-shielded Filler Wires

Type	Hardness, R_B	Yield strength, psi	Ultimate tensile strength, psi	Elongation, %	Table fracture
1	80–82	57,300	71,300	33	1/2 cup
2	81–84	58,700	72,600	30	Full cup
3	78–80	56,600	68,800	31	Full cup
4	83–85	61,800	73,400	28	1/2 cup

and surface tension were overcome. The results were wide, slightly concave welds with good wash at the side walls or fillet legs.

To minimize the loss of alloys by oxidation, various filler wires were investigated. The important effect of the loss of alloy is a loss in weld quality and strength. To determine the quality and strength of CO_2-shielded filler wire deposit, the following procedure was used. Multipass groove welds were deposited in 1-in. thick low-alloy steel plates. Plate edges were prepared by beveling with an oxyacetylene torch. Two beveled plates were fitted on a backing bar with a 3/8-in. root opening to form a welding groove having a 60-deg included angle. Deposits from four filler wires conforming to MIL Spec. E-15599 were tested (see Table 1).

As-welded transverse tensile properties of procedure test plates made with filler wire No. 1, Table 1, are indicated in Fig. 2. Tensile fracture has occurred in the base material at an ultimate strength of 75,400 psi. Side-bend specimens in Fig. 3 exhibit the excellent weld quality and the high ductility of the weldment. The soundness of the deposits is apparent in the macrospecimen in Fig. 4.

Having overcome the difficulties inherent in the CO_2-welding process, preliminary approval by the designers was sought. For approval, 1-in. plates beveled at a 45-deg angle with a 1/2-in. land were attached to a 6-in. round with 5/8-in. fillet welds. To the same round, 5/8-in. plates with squared edges were attached with 7/16-in. fillet welds. The test specimen was sectioned, macroetched and submitted for approval.

In the process of developing the preliminary test specimen, it was established that the best angle to hold attachments during welding was 30 deg, $\pm 2\frac{1}{2}$ deg from the horizontal. With attachments held at this angle, flat one-pass fillet welds could be deposited without undercutting either fusion line.

Preliminary approval of the CO_2 process was granted with a minor provision. The provision was that the land be reduced to 1/4 in. on all attachments over 5/8-in. thick by increasing the beveled surface. Square-cut edges were approved for all attachments 5/8-in. thick or under.

With the process approved, it was then necessary to prepare full-size test assemblies. These were made in order to prove the physical-strength properties of full-size weldments.

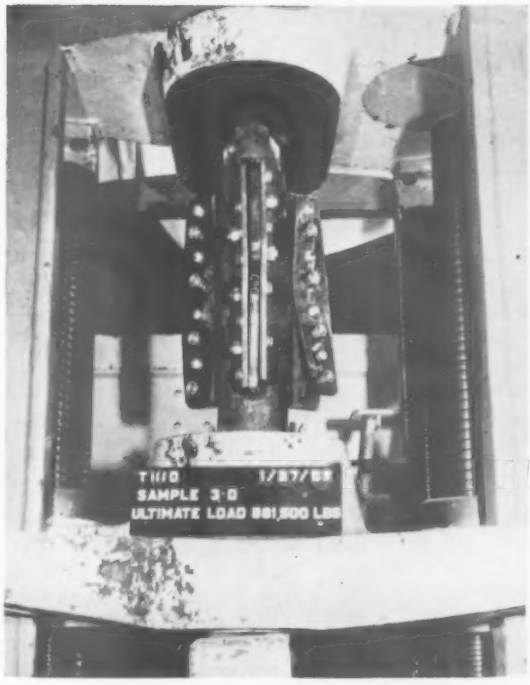

Fig. 6—Full-size test specimens after loading. Failure occurred by shearing the high-strength bolts

Full-size test assemblies (Fig. 5) welded by the CO_2 process were designed to resist a minimum tensile load of 850,000 lb. None of the four assemblies tested failed until the tensile load passed 880,000 lb, more than 30,000 lb above the minimum specified. No failure occurred in the welds. Figure 6 is a typical failure. All tests failed by shearing the 1-in. high-strength bolts. In no case was there any evidence that the yield strength of the welds had been exceeded.

Material Preparation

Material preparation required unusual procedures in order to meet the specified dimensional tolerances. Since leg ends transmit stress by direct contact, it was necessary to machine them to a surface roughness specification of 250 microinches. A special saw-type mill cutter with a positive clamping fixture was used to prepare tower legs to meet this specification. Each tower section, approximately 32 ft long, was composed of three legs to be bolted together in the field. To assure close matching of legs in a given section, it was necessary to cut all three legs to length while at the same temperature.

The 3000 different attachments and gusset plates were oxygen cut to size using oxygen and natural-gas torches on a four-torch pantograph. Movable templates were provided for each shape to permit the positioning of large plates on the cutting table. Any attachments that were over 5/8-in. thick and required edge preparation were positioned in a fixture

so that the edges to be beveled were in a horizontal plane. Beveling was done with twin oxyacetylene cutting torches.

Bolt holes in the 3000 attachments were drilled by ganging four plates together. Templates were provided for each size and shape.

Fixtures for Preheating and Welding

Production schedules required the fabrication of tower legs at a rate of one per hour. Fixtures for preheating and welding thus became vital parts of production planning. Preheating requirements of an area four times the thickest alloy member and the large number of attachments joined to each leg made it advantageous to preheat the entire leg.

All tower legs, fish tails, gussets, guy attachment legs and flange connections were preheated in a batch-type oven. High-temperature forced air was the heating medium. Location of the oven was between the area where parts were prepared and the area where automatic CO_2 and metal-arc welding fixtures were located (Fig. 7).

The arrangement provided an even flow of material from the preparation floor through preheat to the welding station. To minimize the need for applying heat to maintain the minimum interpass temperature, parts were preheated to 400° F which was 100° above the specified minimum of 300° F. The only local preheat that was required was for the few guy attachment lugs and flange connections. These were preheated with natural-gas burners. The welding was manual with low-hydrogen electrodes.

Major factors governing the design of the automatic CO_2-welding fixture were (Fig. 8):

1. Ease of loading and unloading legs.
2. Fast, secure clamping of legs.
3. Simplicity in setup.
4. Accurate location of attachments during welding.
5. Suitable carriage for CO_2-welding heads.

To provide ease in loading and unloading, two movable lathe heads were located on a 50-ft bed. Heads were moved in or out by quick-acting hydraulic cylinders. With this arrangement, the 5000-lb tower legs could be moved in or out of the fixture in about one minute. The holding devices were three-jaw chucks.

To simplify changing setups for the various leg designs, the lathe-head face plates were provided with removable jigs by which the end attachments were held. Interchangeable pedestal-type jigs were located on the fixture bed for holding mid-span attachments. Face plates were rotated to predetermined fixed stops to locate the end attachments at the proper angle for welding. Pedestal jigs had tables at the desired angle. Attachments were located on the jigs with tapered pins extending through the predrilled bolt holes into locating holes in the jigs.

Two welding carriages were located on a precision track extending the length of the lathe bed. When engaged, carriage travel could be varied between 0–30 ipm. When disengaged, carriages were free wheeling and could be moved at will by the operators.

Standard long-neck CO_2-welding torches with vertical and transverse adjustments and the necessary wire-feed mechanism were mounted on the carriages. Readily accessible welding controls were suspended from the carriages within easy reach of the operators in order that minor adjustments could be made during deposition. Each of the two welding heads had a 500-amp constant-potential rectifier as a power source. These were located behind the welding fixture.

Sixty tanks in three groups of 20 each were connected to a manifold and piped to the welding station. By these means, a constant supply of CO_2 shielding gas was available at the welding machines and the danger of drawing liquid CO_2 from the tanks was eliminated.

Welding

Legs were moved from the preheat oven to the welding fixture by an overhead crane. They were lowered onto pillow blocks and held while the lathe heads were moved into position and clamped. Pillow blocks supported the major load and eliminated sagging of the legs between heads. As legs were being positioned, several attachments were removed from the preheat oven and transported to the welding station on a hand truck. As welding progressed, additional attachments were supplied to the automatic welding machines by the helper.

Deposition was with $^1/_{16}$-in. diam wire fed at a constant rate. Table 2 lists the welding variables used to deposit fillet welds by the automatic CO_2 process.

Welding procedures should always be designed to keep operator adjustments to a minimum. In this project, welding procedures developed during qualification tests kept all welding variables constant except carriage-travel speeds. The only variable that required the operators to make this adjustment was the thickness of the attachment being welded to the leg. Supervisors frequently checked the welding set-

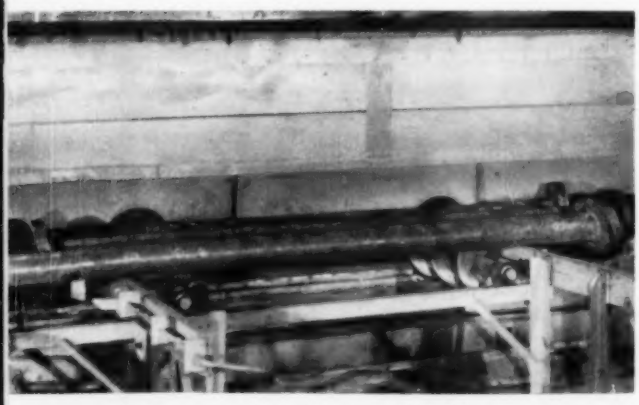

Fig. 7—Oven for preheating parts to 400° F

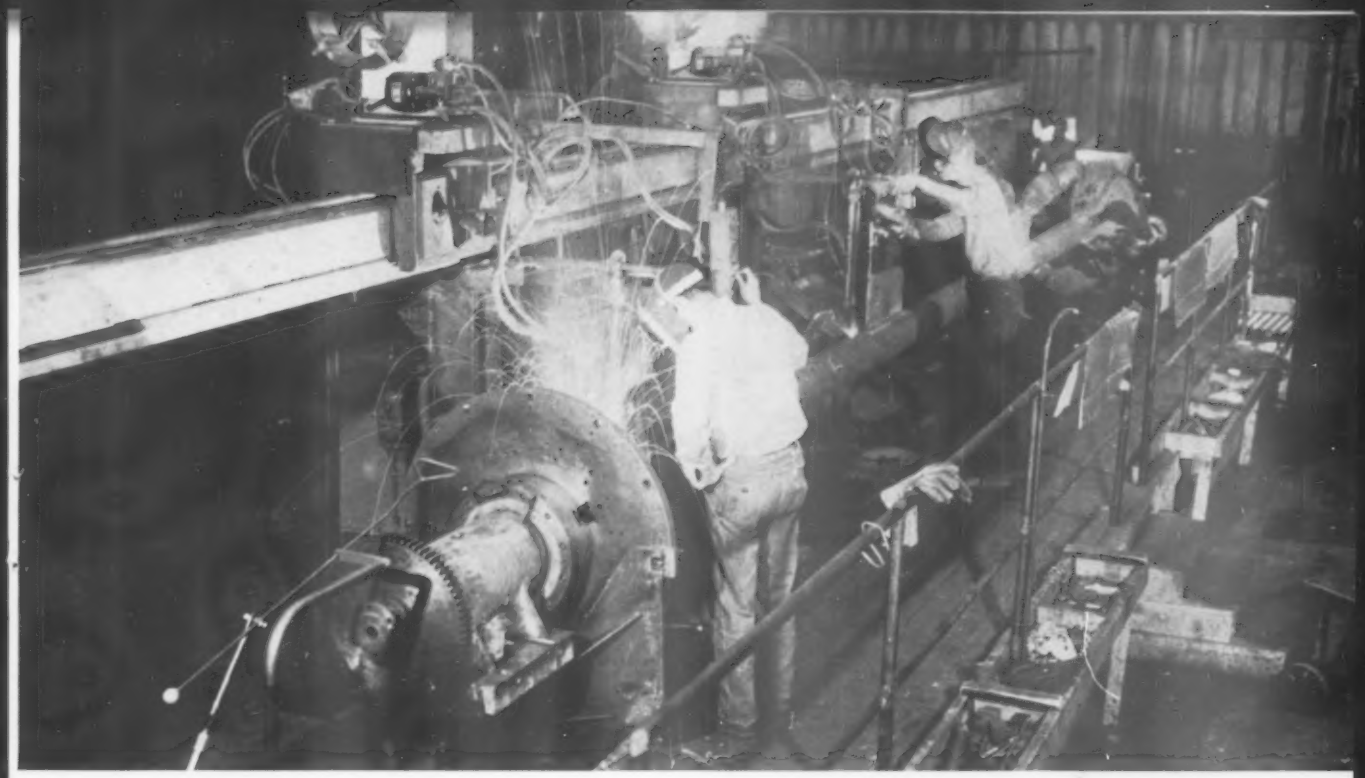

Fig. 8—Over-all view of automatic welding fixture

ups during automatic welding. The most critical item, the one checked most frequently by supervision, was carriage-travel speed.

When automatic welding had been completed, legs were removed from the welding fixture and taken to another station where end return welds were made with manual metal-arc electrodes.

Legs which required guy attachment lugs or flange connections were located at another welding station where the legs were locally heated to maintain interpass temperature while fit-ups were made.

Scheduling parts through the preheat oven was an important factor in obtaining high welding rates. It was necessary to keep a steady flow of material to the automatic welding machines to meet the one per hour production rate.

After assemblies had cooled to room temperature, all welds were visually inspected for cracks, undercutting and fillet size. Inspections were performed by both shop quality-control personnel and a Navy inspector.

Conclusions

An attempt has been made to relate the choice of an automatic welding procedure to existing shop facilities and to the many other operations preceding actual welding.

A relatively new process, CO_2 welding, was adapted to a fabricating facility when an old established process, submerged-arc welding, would have placed excessive burdens on equipment and preparatory operations.

The new process proved to be fast and reliable with all the advantages of open-arc welding but without the disadvantages of post-weld cleaning. Welds proved to be of high quality and fully acceptable for the application.

Table 2—Welding Variables Used to Deposit Fillet Welds by the Automatic CO_2 Process

	$^5/_{16}$-in. thick attachments	1-in. thick attachments
Wire feed	340 ipm	340 ipm
Arc voltage	39 v	39 v
Amperes	400–450	400–450
CO_2-gas flow	45 cfh	45 cfh
Welding speeds	14 ipm	7 ipm

The authors feel that other fabricators, through engineered welding procedures, will find the CO_2 process to be another useful tool for making heavy structural weldments.

Acknowledgment

The authors wish to express their appreciation to E. C. Smith, director of research, Republic Steel Corp. and P. L. Bruhn, manager, Truscon Division, Republic Steel, for the opportunity to present this paper.

Acknowledgment is also given to W. A. Black, assistant director of research, for his encouragement and valuable assistance.

The contributions of L. Rigby, welding foreman, Truscon Division, and R. Peterson, Electromechanical Research Center, were particularly valuable to the development of this paper.

The photograph in Fig. 1 was supplied by Continental Electronics.

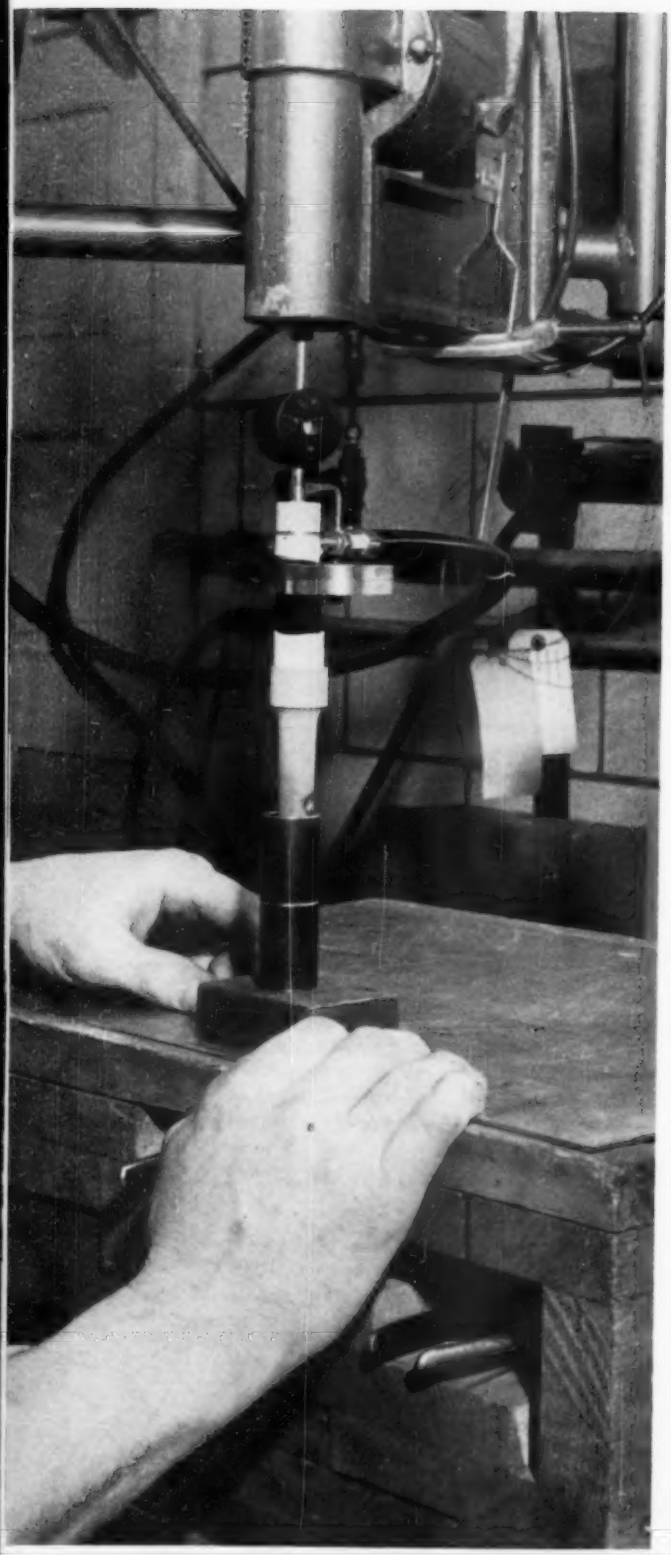

Fig. 1—Laboratory internal-welding equipment

Internal Welding

of Tubes to Tube Sheets

can be accomplished by inserting a tungsten-arc torch through the tube-sheet hole to the rear of the tube sheet, and fusing the tube to the tube sheet at that point

BY E. W. ROWLANDS, JR.
AND J. C. COOKSEY

In the course of the past decade, the role of the tube joint in heat exchangers has developed at a very rapid pace. This became necessary as temperatures and pressures increased for heat exchangers in chemical, petroleum and steam power plants and, especially, as a more critical need developed in the nuclear-energy and atomic-power fields.

The rolled or expanded tube joint, has been, and still is, used for the majority of heat exchangers fabricated. A properly designed and expanded tube joint is more than adequate for most requirements and is proved by the many thousands of trouble-free pressure vessels in service.

For more critical service in the power, petroleum and chemical plants, a welded or combination expanded-seal welded tube joint is necessary to meet the severe working conditions and to give trouble-free service. A few of the more common of this type tube joints, now in use, are shown on Fig. 2.

For nuclear-energy and atomic-power installations, tube joint requirements are more critical than ever. A failure of a tube joint could cause extensive damage to equipment, even loss of life. For many of these requirements, tube joints similar to those shown in Fig. 2 are adequate. Joints of this type or refinements of same as shown in Fig. 3, are suitable for most heat exchangers where the radioactive or corrosive fluid is in the tube side. The integrity of these joints is controlled by surface-inspection methods on the finished product and by a very rigid qual-

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Paper presented at AWS 41st Annual Meeting held in Los Angeles, Calif., April 25–29, 1960.

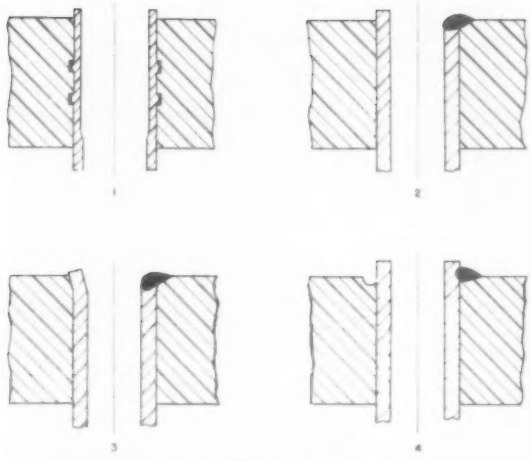


Fig. 2—Standard tube-attachment methods

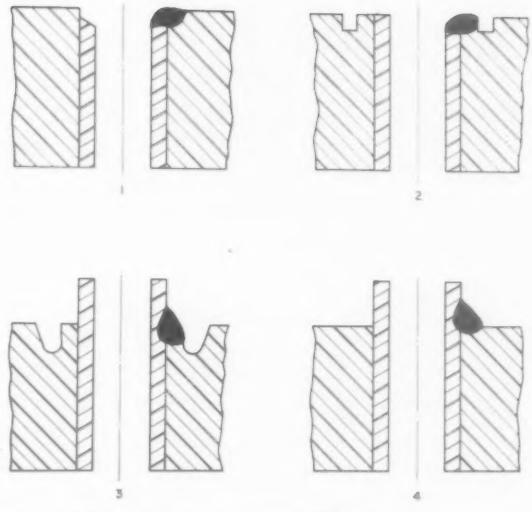


Fig. 3—Welded tube attachments refined

ification procedure, which must necessarily be followed in fine detail in actual production.

Where service conditions are most severe, as for example, when the corrosive or radioactive fluid is on the shellside, a crevice-free type of tube joint that can be radiographed, to insure the best of quality, is that most desired. This paper traces the development of such a joint and the equipment necessary to produce it.

Tube-joint Criteria

The designing of a tube joint for highly critical service, having corrosive or radioactive materials on the shellside, was begun by establishing the basic criteria for such a tube joint. The criteria agreed upon were as follows:

1. The tube joints must be crevice free so that no radioactive material could become trapped and create a dangerous condition.
2. The tube joints must be designed so that they could be one-hundred-percent inspected using approved nondestructive inspection methods, primarily radiography.
3. The tube joints must be designed so that automatic welding techniques could be employed.
4. The tube joints must be able to withstand full operating temperatures and pressures involved.
5. The tube joints must be located in an area of minimum physical and thermal stress.

The combination of the five listed criteria imposed conditions for which there was no common method of attack.

A study of the criteria revealed that each criterion was interdependent upon one or more of the others. As in any research or development project, some assumptions must be made. In this case the assumption, which was the basis of criterion 4, was that the tube joint, which was being sought, must be welded.

With this assumption, the first task was to pick a welding process which could be automated to meet the conditions of the third criterion.

Welding Process

From a study of the welding processes, it appeared that the inert-gas-shielded tungsten-arc welding process (hereafter referred to as tungsten-arc welding) would be the most adaptable process to the materials and criteria, because of the simplicity of controls and operating equipment. The tungsten-arc welding process could be made an automatic process quite easily, since it was only necessary to control the arc length, travel speed and the welding current, to control the weld with this process.

At this point in the planning, straight fusion welds made without the use of additional filler metal were the only type considered. By making the tungsten-arc fusion welds automatically, the possibility of human error could be reduced to a minimum and the physical or mental condition of the operator during the course of the days production would not affect the quality of the work performed.

In order to evaluate the welding process properly, some thought had to be given as to what type of tube joint was going to be used. The first criterion of the tube joint indicated that the tube must be attached to the tube sheet without having a crevice. To make a tube-to-tube-sheet attachment without a crevice, one could either fill the crevice with material to seal it off, as by back brazing, or eliminate the crevice altogether. The application of back brazing with high-temperature brazing materials was quite expensive and limited to small size units which would fit into the controlled-atmosphere furnaces. At this point, the authors took the altenative of trying to eliminate the crevice altogether.

It was obvious that the tubes could no longer be welded to the face of the tube sheet, but must be welded to the back of the tube sheet, to eliminate the crevice. The design of shell-and-tube exchangers

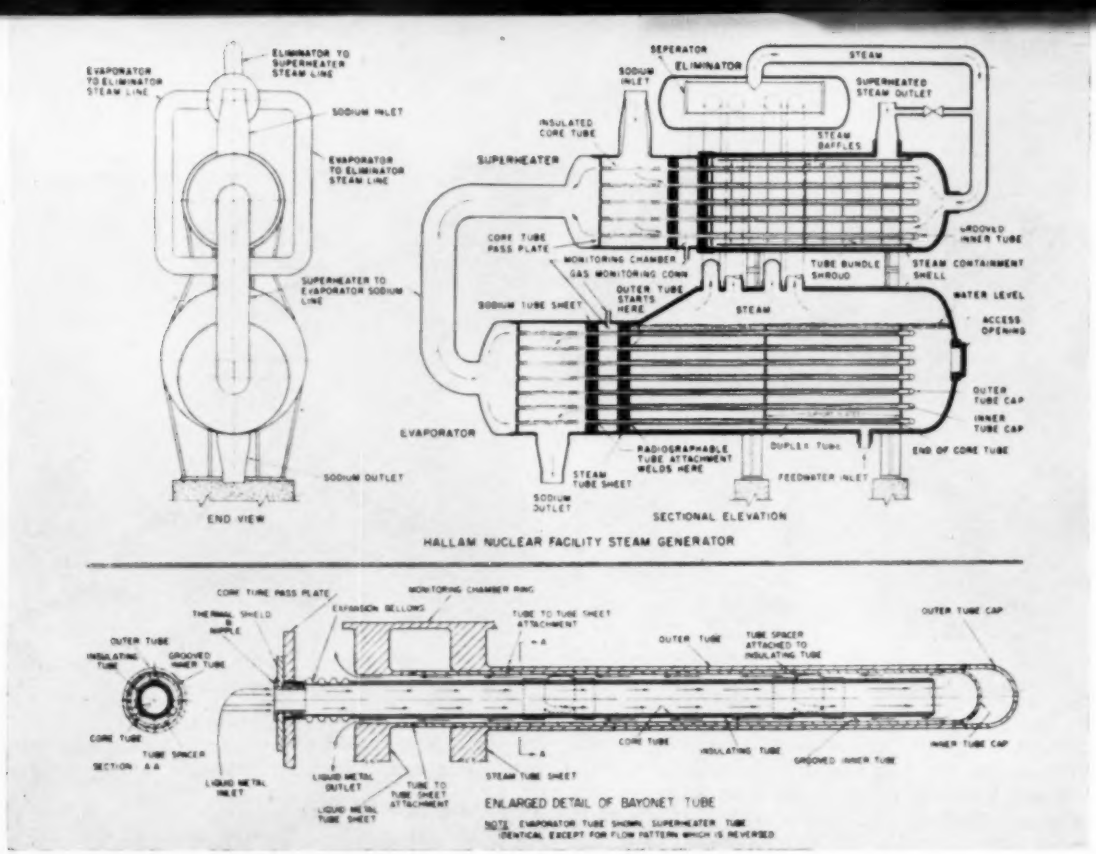


Fig. 4—Atomic-power heat-exchanger design

(see Fig. 4) is such that a number of tubes must be attached to the tube sheet to facilitate the exchange of heat. Design wise, the greater the number of tubes per unit area of the tube sheet, the more economical the unit. From the welding standpoint, the greater the number of tubes per unit area of the tube sheet, the more difficult the attachment problem becomes. This is especially so when one considers the welding of tubes to the rear of the tube sheet. It could be seen that it would be next to impossible to weld the tubes to the rear of the tube sheet using standard manual fillet-welding techniques without trying to apply automatic equipment in the confined space between the tubes. Therefore, a plan was developed for welding the tube to the tube sheet from the inside of the tube hole. The plan was to make a weld by inserting a torch through the tube-sheet hole to the rear of the tube sheet and fusing the tube to the tube sheet at that point. (The above type of welding will hereafter be known as internal welding.) Internal welding of this type would allow the welding of many tubes to the tube sheet without obstruction.

In order to investigate the possibilities of making the internal type of tube joints, a laboratory setup was made using standard tungsten-arc torch parts, with an attachment to allow the torch to rotate about its axis. Figure 1 shows this early setup. From past welding experience, it was known that it was much easier to fuse similar thicknesses of materials, so that the first attempts at this internal welding were made using two pieces of $2^1/_4$ chrome-1 moly tubing. It was assumed that, if a weld could be made between two pieces of tubing, performing the welding from the inside, some arrangement could be made to machine tube like lips on the backside of the tube sheet. It was also evident that such an arrangement would produce better radiographic conditions because of the similar thickness of material on both sides of the weld area. Butt welds between two pieces of tubing were tried with the welding torch on the inside. After a number of experimental changes were made, a fusion weld was accomplished between two pieces of tubing, welding from the inside of the tube. At this point it was evident that internal tungsten-arc welding was possible. Even though internal welds were made, the quality of the welds left much to be desired.

Joint Design

In order to improve the quality of the welds sufficiently to meet radiographic weld standards, our attention was turned to the development of a joint design. The initial internal tube-to-tube-sheet welds had portions that lacked continuity of cross section completely penetrated; other portions that were penetrated left a concave bead on the outside of the tube. Both of these conditions had to be corrected to produce a weld that was fully penetrated, giving a convex appearance on both the inside and outside of the weld. This was deemed necessary in order to meet the high-strength criterion required.

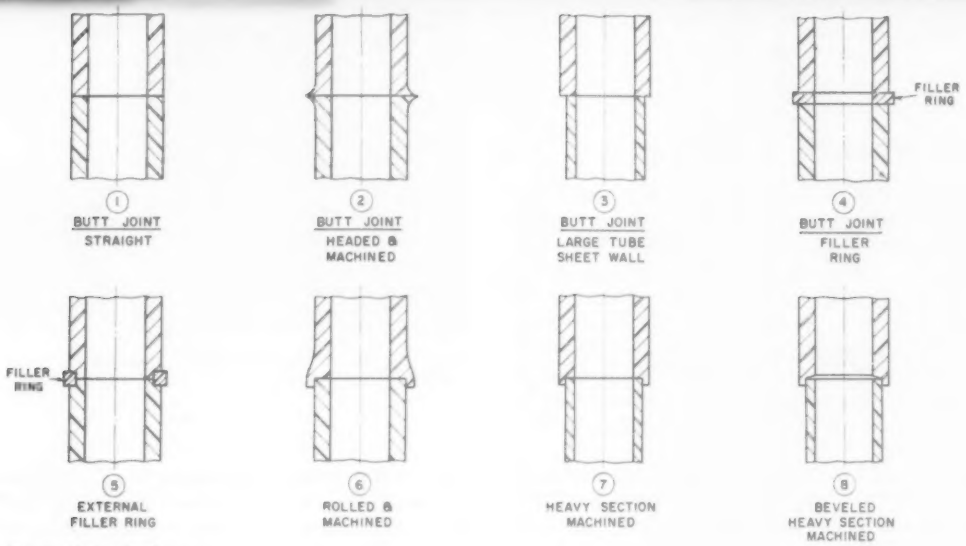


Fig. 5—Tube designs

As already stated, the first work at making an internal weld was accomplished using short lengths of tubing. At the time this work was started, the object was to make heat exchangers of $2^1/_4$ chrome-1 moly materials. For this reason, the experimental work was done using $1^1/_2$ in. OD x 0.083-in. wall tubing of $2^1/_4$ chrome-1 moly material.

It should also be noted that the lab equipment used for the initial welding was held in a vertical position rotating the electrode in a horizontal path. This position for welding was arbitrarily picked to facilitate the building of equipment and the holding of consistent welding conditions. Welding in any other position than the horizontal would have a variable gravitational effect at different points around the weld.

As noted above, the welds made using joints No.1 of Fig. 5 lacked reinforcement, as could be expected without the addition of filler metal. It was obvious that some additional filler metal would have to be added to reinforce the weld and to give additional strength.

The first joint preparation tried was a straight butt joint, prepared simply by squaring the ends of the tubing. This joint preparation is shown in joint No. 1, Fig. 5. During the welding operation, the inside of the tubes was protected with argon gas from the modified tungsten-arc torch, while the outside of the joint was enclosed in a purging fixture filled with argon gas.

The first attempt at introducing additional filler metal into the weld was accomplished by increasing the cross-sectional area of the tube joints as in joints No. 2 and No. 3 of Fig. 5. Joint No. 2 shows the tube sheet side of the joint increased in thickness, and joint No. 3 shows the upset of the ends of the tubes. These joints provided adequate weld reinforcement, but alignment and penetration introduced additional problems. Adequate reinforcement was attempted by the use of preplaced filler rings as shown in joints No. 4 and No. 5. Again, adequate reinforcement was obtained but the alignment problem was increased by the joint design as in No. 4. Joint No. 5 reduced the alignment problems but did not produce the required penetration properties. Assembly difficulties were foreseen with the use of preplaced rings, and this led to the modification of the joint design to those shown in joints No. 6 and No. 7. Both of these designs had advantages over previous designs. Machining difficulties were encountered with joint No. 6, while welding-heat control problems for penetration were encountered with joint No. 7. The penetration problems of joint No. 7 were overcome by the addition of a bevel to the design, as shown in joint No. 8.

Joint design No. 8 appeared to have all the properties necessary to overcome the weld reinforcement and penetration difficulties; also, it offered very good setup and alignment features for rapid assembly. On the basis of these properties, further studies were made using this joint preparation.

The above joint design as developed, using tubing, was adapted to tube sheets by a trepan type of machining on the back side of the tube sheet. A large number of single tube-joint samples were prepared and welded as shown in Fig. 6 to check the reproducibility of the design. Radiographs were taken of these samples to prove the quality of the welds. Figure 7 shows this joint sectioned and Fig. 8 is a photomicrograph of the weld.

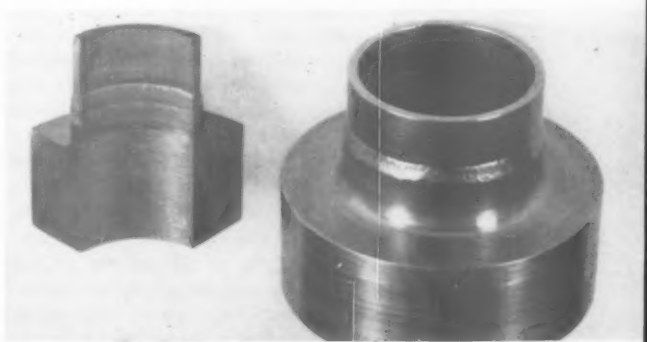


Fig. 6—Welded internal tube-joint samples

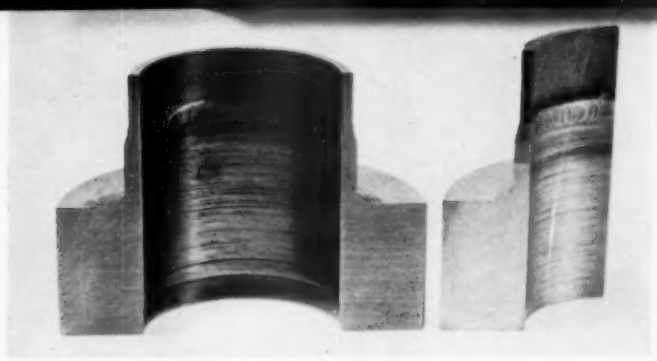


Fig. 7—Section of internal tube-joint sample showing joint configuration

Welding Equipment

During the time that the joint design was being developed, a survey of the commercially available welding equipment was made. This survey showed that adequate equipment was not available to do this type of welding. A program was then set up to design and build the equipment. The welding gun had to be portable, simple to operate and, yet, rugged enough to be used in production. Also, as stated previously, the equipment was to be automatic in order to reduce the probability of human error.

While the needed equipment was being designed, it was learned that another manufacturer had been working on automatic equipment to weld tubes to tube sheets. What is more, they agreed to build a modified version of their gun to our specifications. These modifications consisted mainly of slowing down the rotational speed and making an adaptor for reaching down inside a tube hole. The portion of the gun that extended down into the tube hole was made of copper since it was to carry the welding current to the tungsten electrode. After a period of investigation involving the use of the above-mentioned modified gun, it was evident that this equipment was not compatible with the welding power source that was felt to be necessary for the production of automatic welds. At this point, work was resumed with the original gun design which was adapted to make internal welds, as shown in Fig. 9.

Since this welding was to be done by the tungsten-arc process, means for getting the inert gas down to the welding zone was required, as shown in Fig. 9. Inert gas came into the top of the gun, through a chamber sealed by "O" rings, and passed down to the tungsten electrode. Welding current was transmitted to the tungsten through the copper disks and the core of the gun. To allow the gun to operate over extended periods without overheating, a cooling-water passage through the rotating disks and core was made.

The rotating power to the gun was supplied through a flexible drive shaft similar to that used on several makes of gas metal-arc welding equipment. The end of the flexible shaft connected to the gun was attached to a worm gear which, in turn, powered a ring gear. This ring gear was fastened to the copper core. The other end of the flexible shaft was connected to a variable-speed drive motor. By changing the motor speed, it was possible to vary the rotational speed of the tungsten electrode.

This type of welding gun and rotational power supply was used to fabricate the first heat exchanger employing internally welded tubes to tube sheets. During the fabrication of the first units of this type, it was learned that certain small defects in the completed welds could be attributed to the variation in the rotating speed of the gun. This variation in the rotating speed was found to be in the flexible drive shaft. Any variation in the frictional load of the driving mechanism of the gun caused a change in the rotational speed due to the flexibility in the drive shaft. The welding gun was redesigned so that the rotation of the tungsten electrode was accomplished through a small direct-drive motor. This drive motor was built into the gun, thus doing away with the flexible drive shaft. The rotational speed was then controlled by varying the voltage supply to the d-c drive motor. Making the drive motor an integral part of the gun also improved the portability of the gun.

The first welding-power source used was a standard constant-current rectifier, equipped with water, gas and high-frequency arc-starting controls. Remote current controls were also used with this equipment. This equipment made it possible to set welding conditions and to determine the design of the automatic controls. In an automatic setup, it is desirable to have a power source equipped with electronic or mechanically initiated controls that can make a complete welding cycle. With this type of equipment, the operator would only be required to position the equipment over the weld joint and to initiate the weld cycle.

The complete welding cycle consisted of the following sequences:

1. Start the inert-gas and water flows.
2. After a preset time, initiate the welding arc.
3. Start the drive motor for the rotation of the electrode.
4. After a full 360 deg of rotation, initiate the tapering off of the welding current.
5. After the current has faded to a minimum and has been cut off, allow the inert gas and water to flow for a preset time.
6. Recycle the setup for starting of next weld.

In order to describe more fully how an internally welded tube-to-tube-sheet joint is made, the above sequences in detail are:

(*a*) The weld joint is prepared by inserting the tube end into the tube-sheet preparation. Since this weld is to be a full-penetration weld, the back side of the joint is enclosed in a gas-backing fixture.

(*b*) The gun is then positioned into the tube hole. Figure 10 shows the proper position of the gun in relationship to the weld joint.

(*c*) Closing of the starting switch permits the gas and water flow to start and to activate a preflow timer. The preflow timer is adjustable

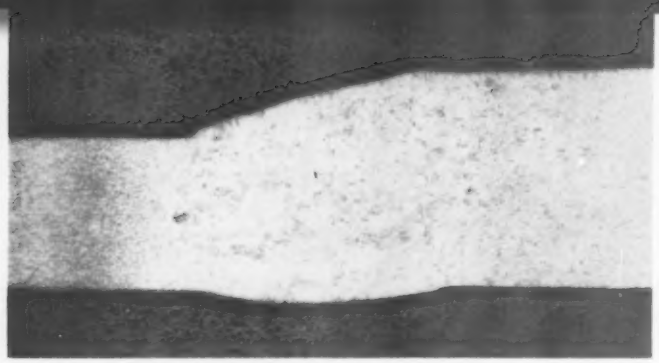


Fig. 8—Macroetched section of internally welded tube joint

This preflow of gas purges both the front and back side of the weld.

(*d*) When the preflow timer times out, the welding contactor is closed and the superimposed high-frequency current is initiated. Once the welding arc is made, the drop from open-circuit voltage to welding voltage operates a relay which shuts off the high-frequency current. (Through experiments, it was found that different materials and tube sizes required different procedures.) Figure 11 depicts the different types of starting conditions that can be obtained. For certain sizes and types of material, it is best to initiate the starting current above the welding current. This produces an almost instantaneous penetration of the joint. The current is then sloped down to the desired welding current at a preset rate. This type of starting is shown by line *AB* in Fig. 11. This hot starting requires that the rotation of the welding gun be started at the same time that the welding arc is established. This is done by a voltage-sensitive relay which is activated by the drop in voltage output of power source, at the initiation of the welding arc. Other sizes and types of materials are best welded when the welding current is started at a very low value and built up to the welding current over a preset time. In this type of starting, the rotation of the gun is not started when the arc is established but after the current has built up to a preset value. The rotation of the gun, in this case, is controlled by a variable current-sensitive relay. This type of starting is shown by line *BC* in Fig. 11, with the rotation of the gun being started at any desired point along the line.

(*e*) When desired welding current has been reached either by the down-slope or up-slope technique, the length of time that the welding current is on is controlled by a weld timer. The time and the rotation speed of the gun are preset so that a minimum full 360-deg rotation is obtained.

(*f*) When the weld timer has timed out, a tail down-slope control is activated. The tail slope control has been set to reduce the welding current down to a minimum, at a given rate, before the arc is extinguished. The extinguishing of the arc raises the voltage, from the arc voltage, to the open-circuit voltage. This down sloping of the welding current, before the arc is extinguished, eliminates craters at the finish of the weld.

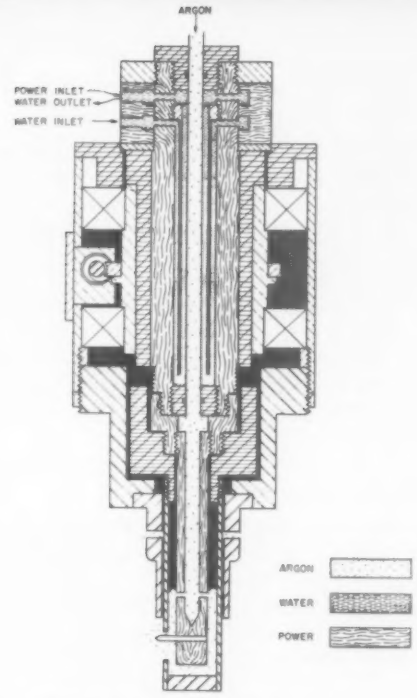


Fig. 9—Section of automatic tungsten-arc welding gun adapted for internal welding

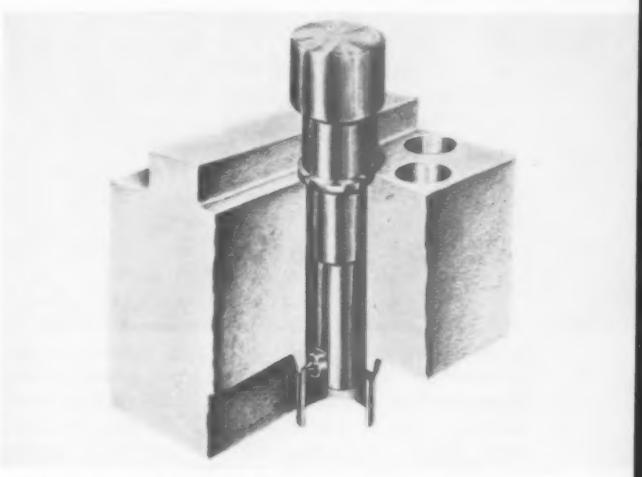


Fig. 10—Section of tube sheet showing the position of electrode for internal welding

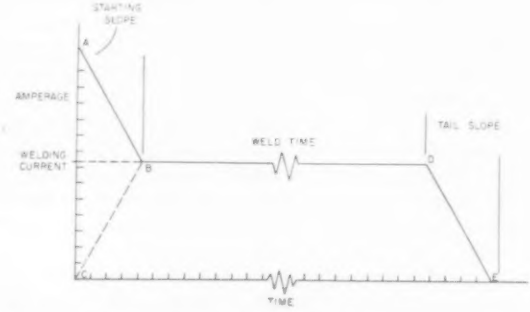


Fig. 11—Welding current vs time diagram showing controlled slope

(*g*) After the arc has been extinguished, the flow of gas and water continues for a preset time to cool the welding equipment and supply adequate shielding of the weld. When the gas and water flows shut off, the equipment is recycled and ready for the next weld.

The final welding conditions were arrived at after a long development period. Variables, such as welding current, arc length, rotation speed, gas flow and arc position, were studied. A separate set of conditions was set up for each type of material and tube size required.

Welding Conditions

As noted before in this paper, the $2^1/_4$ chrome-1 moly material was of primary interest, because it met requirements of operating conditions in the heat exchangers under consideration. Therefore, the primary study was devoted to samples of chrome-moly. The characteristics of the material, such as thermal conductivity and heat of fusion, as well as weldability, had to be taken into account in order to set the welding conditions. As in all welding, the current and speed must be adjusted for the position of welding, in order to control the size and shape of the weld. As noted previously, it was decided to weld in the horizontal plane. Experiments with welding in the vertical plane indicated that either the welding speed or the welding current would have to be varied throughout the welding cycle to produce a weld of constant size and shape.

Although welding in the vertical plane would be a definite assembly aid, since units with long lengths of tubing would be more difficult to assemble vertically, the horizontal welding method was chosen for its simplicity of welding control.

Even when welding in the horizontal plane, a certain amount of difficulty was encountered trying to get a consistent weld size. This was due to the temperature difference in the base metal at the beginning and at the end of the weld. At the end of the weld, the joint has been preheated by the heat input at the beginning of the weld and, under constant welding current and speed, the weld proper becomes larger and, therefore, harder to control, as the weld is completed. With this thought in mind, preliminary experimental samples were welded at high speeds with high-current input. It was soon found that welds made in this manner were fairly consistent in size and easy to control but, at the same time, were poor in quality. The welds were very porous. Further experiments indicated that the porosity was reduced by slowing the welding speed and lowering the welding current. With this procedure, the weld nugget was held molten long enough to allow the gas to escape, thus reducing porosity. Further reduction in porosity had to come from the metal itself in the form of cleanliness, quality and chemistry. The welding conditions for chrome-moly were set at a point of balance between the allowable porosity level and acceptable weld variations, with the quality of the weld dependent upon the base metal.

Further experimental investigation of the internal weld on stainless steels indicated that the problem of porosity was greatly reduced with this material.

Quality Control

Criterion No. 2 demanded 100% inspection of all tube joints. To meet this criterion, it was observed that it was possible to place a film around the weld and to insert a radioactive source inside the tube and, thereby, radiograph the complete weld. Radiographic standards of quality were set up as follows:

1. The maximum size of the porosity shall not be greater than 0.025 in. on the film as measured by comparator.
2. The out of roundness of any porosity spot shall not be of a greater ratio than $1^1/_2$ to 1.
3. There shall be a maximum of 2 spots per weld over the entire circumference of the tube-to-tube-sheet attachment.
4. The proximity of these spots must not be closer than $^1/_8$ in.
5. No tail shall be indicated on the porosity spot.

The radiography technique used was sufficiently good so that a penetrametor 0.005-in. thick would show an indication approximately 0.010 in. in diameter for a tube-wall thickness of 0.083 in.

Conclusion

After the final step in the development of the tube joint had been taken, a model heat exchanger was built and tested over hundreds of hours of operation and many thermal cycles, without a single tube-joint failure. This series of test was proof of the ability of the tube joint to withstand the physical and thermal stresses for which it was designed.

This tube joint is not the complete answer to all applications for highly critical tube attachments, but it is a step in the direction of higher-quality automatically welded tube joints. Research and development programs are being continued to investigate the physical limits of the internal tube-joint weld. Internally welded joints have been fabricated in several metals, such as austenitic stainless steels, $2^1/_4$ chrome-1 moly, and 5 chrome-$^1/_2$ moly. A range of tube sizes has been investigated for the determination of size limitations for the internal tube joint. At the present time, tubes of $^1/_2$ in. OD 16 BWG through $1^1/_2$ in. OD 10 BWG, have been welded commercially. It must be pointed out that the limits vary with the type of material to be welded, so that a hard-and-fast rule cannot be applied. Due to the fact that research and development work is guided by the demands of production, complete studies of the possibilities of the internal tube joint have been somewhat limited. Research and development on internal-type welded tube joints will, however, continue and the authors are confident that more uses will be found for this type of tube-to-tube-sheet attachment.

Practical Welder and Designer

Application of Flame Fluxing with Acetylene, City Gas and Propane

can now be commonly found in both production and maintenance

BY LEE S. WADE

Large bronze ship propeller being rebuilt using nickel-silver braze-welding alloy applied by flux-injected oxyacetylene flame

Although the use of flux injected into the oxyacetylene flame is common in this country, only a nominal amount of experimenting has been done in conjunction with oxy-propane gas.

However, the Canadian welding industry has been using this process with excellent results, through the use of an entirely different type of tip. The tips are similar to our oxyacetylene cutting tips (multiflame), having a large center orifice. Also, they have 12 outer slots similar to the regular oxy-propane preheating tips.

A flux-injection tip can be produced by cutting an oxyacetylene welding tip near the outer radius of the bend and then silver brazing an adapter on the end (see Fig. 3A). Low-pressure or injector-type torches require the oxygen port in the mixer to be enlarged by 50% in diameter in order to attain good performance.

The propane-oxygen torch is a high-speed torch because it has been fitted with an injector mixer for operation on low-pressure natural gas or propane and oxygen. Satisfactory operation is assured when used with the natural-gas pressure at 6 oz and LP gas at 4 oz with a 12-ft 6-in. length of No. 14 neoprene hose. Slightly higher pressure is required when longer lengths of hose are necessary. For each additional 12-ft 6-in. length of hose, three additional ounces of propane pressure are recommended.

By using flux injected into either of these flames, the versatility of the torch is enhanced many times. Not only does it assure the proper amount of flux for the operator at all times, but it speeds the brazing operation. It overcomes the vexing problem of restraining operators from using too much flux. It saves prefluxing time, and length of time at which to keep flux soluble as well. It overcomes the rejects caused by too little flux (this makes a porous deposit). It allows the use of joints that have reasonably poor fit-up. It gives a better wetting action when applied to reasonably clean surfaces. It allows the operator superior control of the alloy, particularly at the edge of joints. It requires less filler metal because beads are flat and whirls are almost

LEE S. WADE is Sales Manager, All-State Welding Alloys Co., White Plains, N. Y.

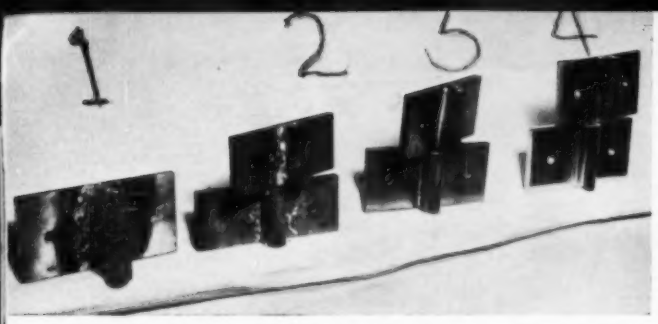


Fig. 1—Four window brackets are shown. The two on the left were chrome plated after brazing with a paste flux. Here plating is curling away from brazed area. The two brackets on the right show smooth finish after flame fluxing and chrome plating

Fig.2—Badly eroded and bent propeller showing the results of salt-water corrosion and the effects of striking underwater objects

(3A)

Fig. 3—These oxypropane tips (left) have 12 outer slots and a large center orifice. Normally, a standard oxyacetylene tip (above) is modified so that the propane tip can be attached to it

(3B)

totally lacking. It does not require the operator to take his eyes from the work to dip the rod into the flux. It eliminates excessive amounts of flux at each separate dipping. It allows layer upon layer to be applied without the bother of excess flux causing pits and pinholes in the deposit. It leaves a neat, clean, nonpeeling surface on the base metal and the filler metal that can be easily chrome plated without preparation by grinding and polishing. It helps to float dirt and oxides to the surface of pitted parts such as ship propellers, etc. It prevents discoloration of the base metal and brazing material in the surrounding area when used on brass, bronze, copper and steel. When used in conjunction with paste flux and silver-brazing alloys on lap and "sweat" fittings, the fluxed flame helps materially to prevent discoloration of the whole area by keeping the surface from oxidizing until the metal has cooled below the oxidation point. Finally, fuel costs are substantially reduced.

Flux-in-flame Principles

Flame fluxing utilizes a carefully compounded flux. It is suspended in solution in a container that can be tied into city-gas, propane or oxyacetylene hose lines. The contents are extremely volatile and flammable; they evaporate quickly when exposed

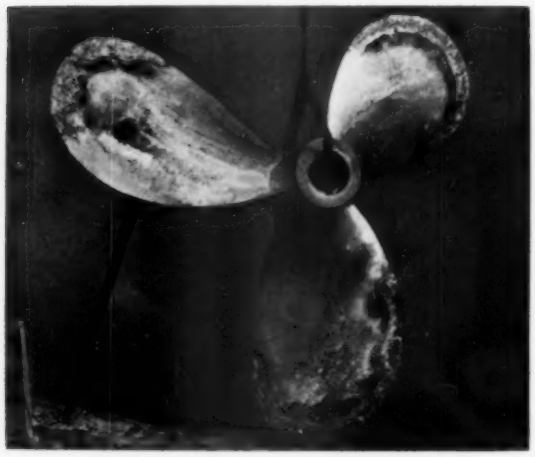
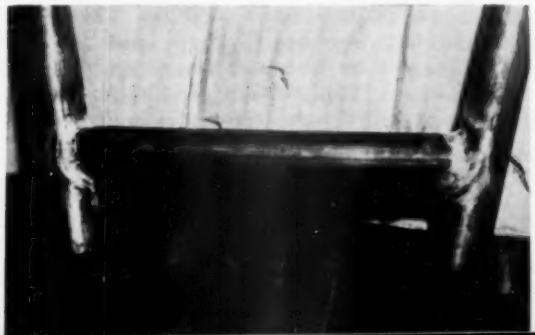


Fig. 4—The leading edge of this repaired propeller has been returned to the original contour using a nickel-silver braze-welding alloy

Fig. 5—Tubular frames braze welded by flux-injected oxyacetylene flame. Production increased 10%, less filler metal was used and appearance was improved



to air. The amount required can be easily controlled at all times. When none is required, the shut-off valve permits the torch to be used normally without dismantling the system.

On the Negative Side

Flux injected in a flame does *not* have a satisfactory wetting action on cast iron, unless used in conjunction with a good grade of powdered boric-acid flux with an iron-oxide additive for the first pass. However, additional layers can be applied after the first is properly tinned. It does not have a satisfactory wetting action on stainless steel unless used in conjunction with a preplaced paste flux. It does not allow the alloy to flow into lap joints. It must be used in conjunction with an alloy that flows near 1400° F for satisfactory results. Only one torch may be used, preferably, with each dispenser. A gas dryer should be used to remove entrapped moisture when city gas or generator acetylene is used. The entire joint area must be prefluxed by brushing the flame over the surface before brazing or braze welding start.

Typical Applications

An excellent production application of flux-injection flames is on window brackets that need to be chrome plated (Fig. 1). A flat piece of cold-rolled steel and a 2-in. long piece of tubing of the same analysis had to be brazed along the back sides of the tubing. The job, when done with conventional paste or powdered flux, always left a rough and peeling area next to the filler metal (a nickel-silver alloy). By using flux injection and this filler metal, a high-strength, smooth fillet on each side is possible on every part, and quality chrome plating results.

Another excellent application for flame fluxing is the buildup of worn and badly eroded ship propellers (see Fig. 2). Lakes, rivers and Northwest waterways are plagued with waterlogged bark, sticks, debris, sand bars, etc., that shorten the life of the propellers. Tugs, rafting logs in shallow water have their "props" literally eroded away by the action of the sand and gravel, much of it stirred up from the bottom by the "props" themselves. The electrolytic action of the salt water also causes the pitting of bronze and the oxidation of steel.

At first, repairs were made with inert-gas-shielded tungsten-arc welding, using mild-steel rod on steel "props." Bronze was used on the bronze "props." Results were good, but not good enough. The gas tungsten-arc process was too slow by the welder's standards and bronze used in conjunction with paste and powdered flux did not get to the bottom of the pits, many of them $^1/_8$-in. deep. This prevented a good bond and some welds were porous. The tungsten inert gas, however, was better than normal brazing methods.

Flux in the flame was tried and proved to be satisfactory. By using a 10%-nickel rod, the filler metal penetrated to the bottom of the pits and floated oxides and dirt to the surface. On the thin and leading edges of the "props," the welder used firebrick as a backup and had excellent control of the braze metal without the bother of excess flux sticking to the firebrick. It also allowed him to deposit a very smooth thin bead or layer of braze metal, saving grinding time afterwards (see Fig. 4).

The first propeller salvaged in this manner was used continuously for a year and a half and, when the boat was removed from the water, the propeller was in such excellent condition that it was not even removed from the shaft, allowing the boat to go right back into service.

Tubular Frames Perfected

One company, until $3^1/_2$ years ago, used flux-coated rods for brazing tubular-steel joints; then it started using flux injected in the flame. Costs were reduced over 10% and rejects proved nonexistent. Only about 2% have been found to have a poor appearance from excessive buildup. Production has been increased by 10% and postweld cleaning has been eliminated. An additional saving has also been made possible, since less filler metal is needed because it flows more smoothly (see Fig. 5).

Washing-machine Parts

At a plant manufacturing washing machines in Toronto, Canada, a pipe standard (see Fig. 6) is brazed by the flux-injection method using oxypropane flame. The standard is part of the mechanism that connects the gear box of the washing machine to the wringer. A low-fuming braze-welding alloy is used. Since changing to oxypropane and the multiflame tips, production has increased and overall costs have dropped 16%. From 800 to 1000 are run off at one time, each one with a smooth brazed surface ready for installation.

At a plant in Hamilton, Ontario, all brazing is done by the flux-injected oxypropane flame. A refrigerator compressor housing (see Fig. 7) has two bundy tubes brazed with 35%-silver solder. A small amount of very thin watered-down flux is

Fig. 6—Washing-machine-wringer drive-shaft housing braze welded with flux-injected oxypropane flame. On this application, production was increased 16%

Fig. 7—Refrigerator compressor housing has two bundy tubes silver brazed using flux-injected oxypropane flame. A small amount of very thin flux is applied first

Fig. 8—Refrigerator cabinet has the corners braze welded by flux-injected oxypropane flame. Smooth appearance eliminated grinding time

Fig. 9—Close-up of washing-machine shaft housing shows the results of two much flux. Here, flux-coated filler rod was used with flux injected into the oxypropane flame

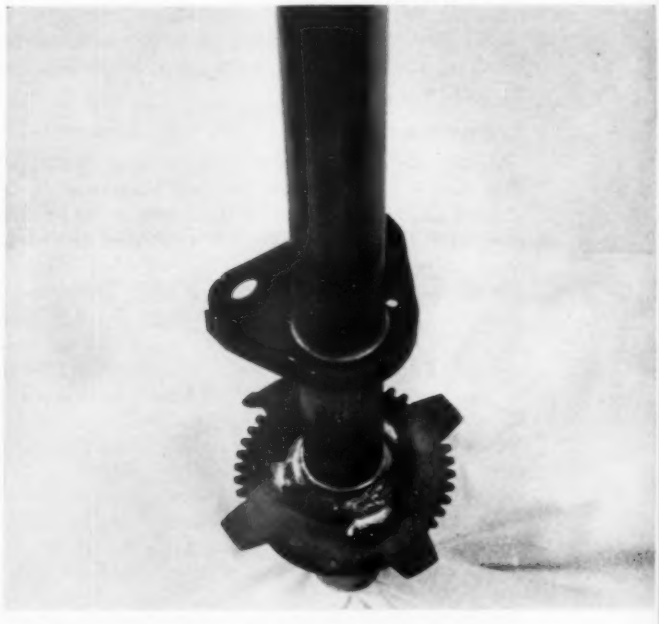


Fig. 10—Appearance of shaft in Fig. 9 when proper amount of flux has been injected into the flame. Surface is smooth and surrounding area is not blackened

applied first (diluted 4 to 1). On this particular joint, capillary flow is not important. Another application in this plant is on refrigerator-cabinet corners (see Fig. 8). Here the material is 19- or 20-gage mild steel. A gap has to be filled where the corners do not quite come together. The joint has a backing plate 0.062-in. thick. Here, a fast application of concentrated high heat is necessary to hold down warpage. Since this spot is not ground afterwards, appearance is a considerable factor, also.

Too Much Flux

A good example of how too much flux affects the appearance of the brazing alloy is shown in these photographs. The joint in Fig. 9 was made with flux-coated rod and fluxed oxypropane flame. The other joint was made with only the flux in the flame (see Fig. 10). When the two are used together (i.e., flux and flux in the flame), the surface becomes mealy, porous and is even blackened in some spots.

When used with propane, the flux turns the flame green, the same as with acetylene and oxygen. It will not corrode the torch valves or regulators.

Conclusions

Flux in conjunction with propane gas is gaining rapid popularity in Canada. There are many

Table I

	Oxy-acetylene neutral flame, cu ft	Oxy-natural gas (neutral), cu ft	Oxy-low-pressure gas (neutral), cu ft
Fuel gas consumption	100	110	43
Oxygen ratio	1.1 to 1	2. to 1	4. to 1
Oxygen consumption	110	220	172
Percentage of combustion with O_2	44%	90%	90%
Btu's released by oxygen	63,800	99,000	97,520
Ultimate flame temperature	6,300° F	5,000° F	5,300° F

advantages claimed such as (*a*) savings in cost, (*b*) availability, (*c*) little or no cylinder handling, (*d*) no cylinder rental, and (*e*) reduced or no delivery charge. However, oxygen consumption will be increased for welding or brazing.

To arrive at the figures in Table 1, the known cost of acetylene gas per 100 ft was taken as a basis. Then the amount of natural gas or propane required to replace it was used as a fair comparison.

The figures given in Table 1 are approximate, as verified by established users. However, it has been difficult to obtain an accurate check on natural gas as it is delivered by pipe line only in Canada. The Btu value of natural gas varies as much as 10% plus or minus, from 1000 Btu per cu ft.

One cubic foot of acetylene requires 2.5 cu ft of oxygen for complete combustion. Of this, 1.1 cu ft is supplied from the cylinder and the balance is from the atmosphere. One cubic foot of natural gas requires 2.2 cu ft of oxygen for complete combustion. Two cubic feet of it are supplied from the cylinder and the balance is from atmosphere. Low-pressure gas (propane) requires 4.5 cu ft oxygen for complete combustion. Four cubic feet of it are supplied from the cylinder and the balance is from atmosphere. One pound of acetylene contains 14.5 cu ft of gas at atmospheric pressure and 1 lb of low-pressure gas (propane) contains 8.5 cu ft gas at atmospheric pressure.

The propane-oxygen welding tips are designed to accelerate combustion of low-cost fuel gas and thus overcome the usual objection to the use of natural gas or propane.

New "Piggy-Back" Flat Cars Have Virtually All-Welded Construction

BY CHARLES W. LYTTON

Some extraordinary arc welding, about 3000 ft per car, has contributed heavily toward highly efficient production of the new 85-ft "piggy-back" flat railway cars. These cars, designed by Pullman Standard Car Manufacturing Co., now are being produced in large quantities in a highly developed and largely automated line at the Butler Pa., plant of this company, believed to be one of the world's largest users of arc-welding equipment. Except for such welding, done at a prodigious rate, production of equivalent cars would be far slower and much more costly. Riveting is almost eliminated, being used in only a few places where joints are specified that may have to be opened in service.

CHARLES W. LYTTON is District Engineer, The Lincoln Electric Co., Pittsburgh, Pa.

Fig. 1—Two of the new 85-ft all-welded flat cars for piggy-back railway service. Each car involves about 3000 ft of arc-welded joints

Fig. 2—First position on the line for flat-car deck assembly, showing one end of the deck plate with four stringer channels tacked in place. In the background is an automatic welding machine that makes the joint between two 42-ft deck plates

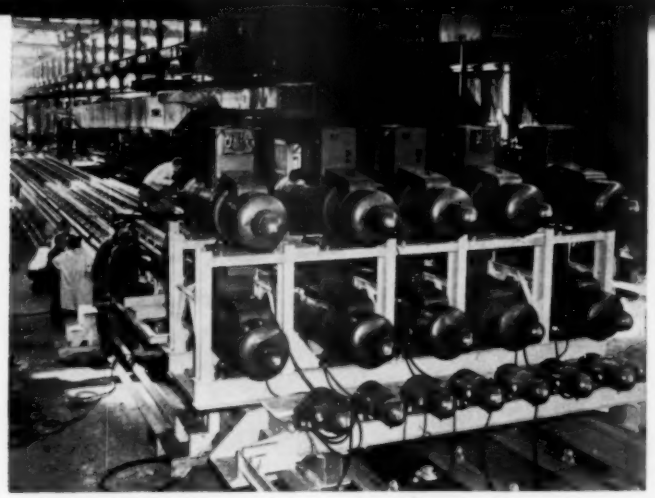


Fig. 3—Huge welding jig that includes 20 automatic heads, ten 1500-amp double-ended motor generators and many other components that make, simultaneously, 10 welds to join four stringer channels and a reinforcing plate to the deck plates. Supported by the crane is a center-sill weldment that, after being inverted, is clamped and tacked to the deck at the far end of the line shown

General

Each of the new cars, Fig. 1, carries two fully loaded highway trailers, each up to 40 ft long, and these can be loaded and unloaded by the same tractors employed for highway haulage. Such tractors can run from end to end of a train of these cars, as each car has hinged bridges that, when lowered across coupler gaps between cars, convert the train temporarily into a roadway, on which loading and unloading are done rapidly. Railway haulage of such trailers is fast and costs less than long hauls on highways, making the cars profitable both to railroads and to motor haulage companies, besides relieving highways of much heavy traffic.

To produce these new flat cars, Pullman-Standard installed, in one 1100-ft long, 90-ft wide shop of the huge Butler plant, a remarkable automated setup. Construction of center sills starts at one end, while the construction of decks starts at the opposite end. These two major components both move toward an intermediate station as structural parts are added and welded into huge assemblies.

At the intermediate station mentioned, the two assemblies are set together, bottom up, air clamped and joined by tack welds. After further welding in a turnover fixture, the assembly is mounted on its own trucks and is advanced along a central track through added stations where welding is completed and some minor subassemblies are added. Finally, the car, substantially completed save for painting, rolls out of the shop at the end of the line next to the area where deck construction started.

With this setup, a crew of welders and cooperating workers builds twelve complete cars per 8-hr day. Only with a well coordinated setup and fast welding equipment, much of it automatic or semiautomatic in operation, could this rate be attained in a shop of this size. Considerable hand welding is needed, especially for short joints and in positions not otherwise accessible, but such hand welding is done rapidly by using AWS E-7018 iron-powder covered electrodes. These electrodes are oven heated to remove absorbed moisture.

Wherever feasible, welding is done by fully automatic or semiautomatic equipment because the welds can be produced at much higher speeds, deeper penetration results and there is much less distortion than for hand welding. Superior penetration is attained because higher current densities are applied. In all full and semiautomatic welding, a low-alloy electrode wire is used along with a neutral agglomerated flux, as nearly all steel employed is of low-alloy high-strength type chosen to keep car weight at a minimum and still attain ample strength and stiffness. Motor-generator units supply d-c current for all welding operations.

Deck Construction

Flat-car deck construction is unusual in several respects and unique in some. Deck plates that subsequently form the tops of the center sill, draft sill and bolsters, are $^{7}/_{16}$ in. thick. Two deck plates, each 8 ft 2 in. wide and 43 ft long, are used per car. These plates are laid, end to end, on a wide roller conveyor that is part of an extraordinary 385-ft fixture. In the initial position, the ends of the two plates are joined by a transverse weld laid down in a double pass against a copper backing by two automatic submerged-arc heads in a gap $^{7}/_{16}$ in. wide. As the gap is filled with weld metal, 100% penetration is attained, plus some slight overflow. This crown is ground off flush later so that the stringers used to stiffen and strengthen the deck will fit properly with the deck plate.

Stringers are 7-in. channels that are laid flat in the fixture, with flange edges against the floor plate. Four stringers, the ends of which appear in Fig. 2, extend nearly the full length of the deck, but there are two gaps near each end where cross structures at bolsters are applied later. Along the center of the deck is a 44-ft reinforcing plate 18 in. wide extending

Fig. 4—Closeup showing some of the ten 85-ft-long double fillet welds that join stringers and a center plate to deck plates. Two men, only one of whom is shown, walk along as the heads are traversed, adjusting controls as needed

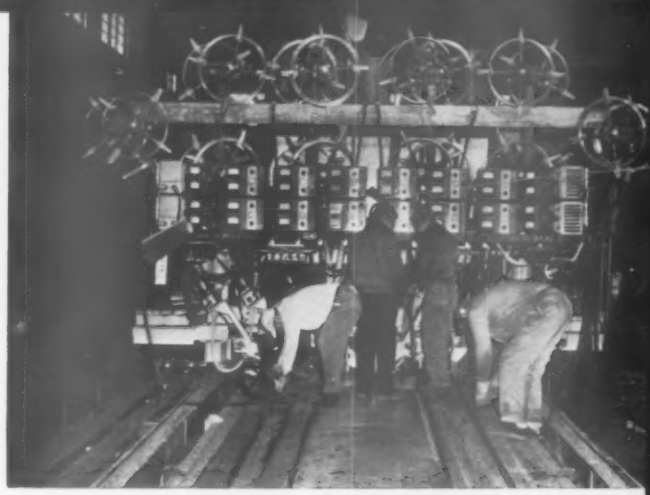


Fig. 5—Another view of the deck welding fixture with wire electrodes feeding from 20 reels, back of which some flux-pickup equipment can be seen. Two men control the machine and are followed by other men using light air hammers to remove slag from the welds

from bolster to bolster. This plate fits between the floor and the center sill whose side plates are welded to the deck after the sill assembly is applied. All deck reinforcements are clamped down hydraulically in initial position on the deck line, Fig. 2, and are tack welded to the deck plate before continuous longitudinal fillet welds are made along both edges of the stringer flanges and of the center plate, at the second position on this line.

Except for gaps at bolster locations, the fillet welds on stringers run the length of the floor, and those at reinforcing-plate edges run its full length. All ten welds are parallel, and each $^1/_4$-in. fillet is produced by two electrodes spaced about $1^1/_4$ in. apart in tandem, one ahead of the other. Of the two arcs, the first penetrates at the root of the fillet and the second builds up the fillet to the wanted size but, as the welding speed is 52 to 58 ipm, the two welds become one, because the two arcs are so close together that the metal does not solidify between them. Flux remains fluid until both electrodes pass each point.

With two electrodes in tandem arrangement for each weld, and with ten welds made at the same time, a total of 20 electrode wires are fed at once, each from its own coil and each passing through its head. This is accomplished by mounting all 20 heads on a carriage that spans the weldment, forming what is probably the largest and most extraordinary welding machine ever built. This machine, shown in Figs. 3, 4 and 5, is made to traverse, by a hydraulic motor, nearly the full length of the deck at the welding speed set. At bolster gaps, current is shut off manually by the two operators who walk behind the carriage, each man keeping track of ten heads.

This welding machine was designed and built by Pullman for use on the new 85-ft flat cars and is, largely, a self-contained unit. As Figs. 3, 4 and 5 show, the machine, besides the heads, includes twenty 150-lb coils of wire (enough for 14 decks), ten double-end motor-generator units of 1500-amp capacity each, a long hopper (holding 1000 lb of flux) feeding to each head hopper, and a complete 5-tank vacuum flux pickup and cleaning assembly, as well as ten 125-v exciters and all controls.

Sliding shoes pick up current from insulated copper bus bars at one side of the track, and grounding brushes move along ground rails at the other side.

Welding current is 575 to 650 amp per arc. In a single traverse, from end to end of the deck, requiring slightly more than 17 min, a total of nearly 850 ft of what are virtually two-pass fillet-weld beads are produced. Operators use gang switches to cut out heads as electrodes cross gaps where bolsters come; they reclose the switches for stringer welds after gaps are passed.

Before the welding starts, the deck plates are clamped with a camber totaling about 3 in. from center to longitudinal edges. This is done so that, when the clamps are released, the warpage caused by the heat of welding is compensated and the deck is flat. It is, then, ready for transfer along the roller conveyor to the third position, where longitudinal edges of the floor plate are oxygen cut parallel to the centerline and the ends are cut off square. This completes the deck assembly, which is now ready for the center-sill assembly. Latter assembly is tacked to the floor after the two units are clamped together hydraulically at the fourth position, Fig. 3, of the 385-ft fixture.

Production of Center Sill

Production of the center sill, which, with draft-sill extensions, runs from end to end of the flat car, starts at the other end of the shop from the floor assembly. This sill is really a long girder having two vertical side plates spaced $19^1/_2$ in. apart. These plates are tapered near each end where they are reduced in width and pass through the bolsters and above the trucks. After the two side plates are clamped in the first station, they are oxygen cut at the same time to template, thereby providing the taper cuts made by torches at each end. Other

torches cut two oblong holes near the center of the plates.

After transfer to a jig at the second position, end plates and separator plates are added and are welded by an automatic head on a support arranged to move from end to end of the fixture. In the next fixture, the bottom tie plate, bolsters and draft sills are added to the center sill but are only manually tack welded into position. When tacking is completed, a special lifting cradle supported by overhead hoists on an overhead rail moves the assembly to a roll-over jig supported on trunnions.

While in this jig, 23 manual arc welders and eight welders using semiautomatic submerged-arc units make a large number of welds that tie together most of the components of the center-sill assembly. Semiautomatic submerged-arc welding is used chiefly on the long welds, especially those that join the bottom plate to the two side plates. Trunnion mounting enables welders to bring each weld into convenient downhand position. When these welds are completed, the assembly is set on a track buggy, bottom up, and then is advanced to the end of the long conveyorized fixture on which the deck has been welded, as described above. Air lifts on the buggy raise the sill assembly to proper height for longitudinal motion above the floor assembly.

When the sill assembly is set in proper position on the floor assembly, air hold-down clamps on the bridges, that are advanced along the tracks, press these two major assemblies firmly together so that they can be tack welded in preparation for the many long welds to follow. Some cross ties also are added and tacked at this station. Then the tacked assembly is removed by an overhead crane and is set on horses for final welding where previously tacked.

While in this position, semiautomatic submerged-arc welding units are employed to complete the joints. These include the long welds that fasten the edges of the center-sill web plates to the deck plates. There are also two automatic welding machines that weld the center-sill bottom cover plates together in three or four passes.

Completing the Assembly

In what is called "Station No. 4," there are double-trunnioned turnovers that are adjustable along a track to facilitate loading the huge assembly. Two 12-ton hoists are used for the transfer. When in this turnover, transverse side sills are added and are welded to the deck bottom after which so-called "rub rails" are welded along floor edges. These rails project about 10 in. above the deck and have rolled beads along the top edges. In effect, these rails form low sides along the platform and constitute guard rails intended to prevent tractor and trailer wheels from running off the floor in loading and unloading.

Long welds in this station are produced by eight semiautomatic submerged-arc welding machines whose control units are on a platform at one side of the assembly. Each control unit includes a closed container holding 100 lb of flux kept under 30-psi air pressure connected through a flexible-rubber tube to the gun, which is moved by hand. Both flux and $^{5}/_{64}$-in. wire feed automatically through the tube whenever the operator pulls the gun trigger. He advances the gun manually in making welds but does not have to stop for filling a cone with flux.

Current of 450 to 500 amp is applied in making these welds that run from end to end of the car and is supplied by motor-generator sets, one of which is beside each welding-machine unit. Eight units are used both to keep the pace with work at other stations and to avoid using long hose connections from each unit to its gun. Besides the eight welding machines for long joints at this station, there are 27 welders using conventional hand electrodes for short arc welds. Many of the hand welds are for fastening crossmembers to the center sill and to the rub rails. By using turnover supports at this station, the work is easily set in successive positions where all welds are made in convenient downhand position, but the weldment is so large that some welders have to stand on short ladders to reach points where some welds must be made, as the trunnion axis is about five feet above the floor.

After welds in this turnover are completed, the weldment is picked up by the same hoists that loaded it and set onto the standard railway roller-bearing four-wheel trucks on which the car runs in service. These trucks rest on a track that runs through the center of the long shop, and the car is moved along this track between succeeding operations and finally is towed out of the end of the shop for transfer to the paint shop in another building.

In the first station on this track, diamond anti-skid plates are tacked in place, by manual arc welds, in two rows where these plates form treads along which tires of tractors and trailers roll subsequently in loading and unloading. Specifications call for some wood decking between the skid plate rows. To fasten this decking, studs are welded to the floor at intervals by a special resistance-type stud welding machine.

At the next station, all skid plates are fastened permanently to the floor by continuous hand arc welds. Then the car is advanced to the next station where, after temporary detrucking, side bearings are riveted in place to level the whole structure. Wood decking then is applied and is fastened by running nuts onto studs in recesses where the nuts are flush with the deck. Trailer hitch assemblies, designed so that they retract into the floor but can be elevated to fasten the tractors to the car, are then tacked into position.

In the next and final assembly station, tractor hitches are hand arc welded permanently in place and many small accessory parts are fastened by the same means to complete the car, save for painting. Thus, it can be seen that each car is an almost completely arc-welded structure. In total, a day's production amounts to approximately seven miles of welding.

Society News

Pittsburgh Beckons AWS Fall Meeting

Preparations for this year's National Fall Meeting at Pittsburgh, Pa., are now under way. During September 26–29, members and guests of the AMERICAN WELDING SOCIETY will meet at the Penn-Sheraton Hotel for the presentation of a varied program of technical sessions and social activities. Located in the center of Pittsburgh's famed triangle, the hotel gives easy access to the area that has undergone one of the most spectacular redevelopments in the country.

Although the main emphasis of this year's fall meeting will center around the technical papers program, other events of interest are being scheduled. Plant tours have been arranged tentatively, for a one-day visit to the Shippingport Atomic Power Station of the Duquesne Light Co., and the American Bridge Co. of Ambridge. Another tour is being arranged for visits to the New Kensington Works of Alcoa and the Brackenridge Works of Allegheny Ludlum Steel Co. An interesting Ladies' Program is in the preliminary stages and will be reported in detail at a later date.

Of the 17 sessions scheduled for the technical program, four are sponsored by the American Society of Civil Engineers and two of these are co-sponsored by the Column Research Council of the Engineering Foundation. In addition a session on nondestructive testing is partly sponsored by the Society for Nondestructive Testing. This fall, the 51 technical papers to be presented will range over a wide field of subject matter with emphasis on the growing field of welded structural design and fabrication.

In keeping with the policy of previous years, the National Fall Meeting will not include a welding show. The calendar of technical sessions giving the title, author and time of presentation was published in the June issue of the WELDING JOURNAL. Further details on other activities of the program will appear in August.

Welcome

•Sustaining Member

Effective May 1, 1960:

Bucyrus-Erie Co.
South Milwaukee, Wis.

Bucyrus-Erie Co. is the world's largest manufacturer of power cranes and excavators. It is also a large producer of drilling machinery. Other Bucyrus-Erie lines include railway cranes, dragline buckets, drilling tools and specialty items for use with excavating and drilling machinery.

The firm has four plants, including one at Guelph, Ont., Canada. An affiliate, Ruston-Bucyrus, Ltd., is located in Lincoln, England. Representatives and distributors are located throughout the United States and in other principal countries of the world.

Sustaining Member Representative—J. I. Andreini.

HUB OF THE WORLD'S HEAVY INDUSTRY

Pittsburgh's famed "Golden Triangle" will be the scene of the 1960 National Fall Meeting of the AWS to be held at the Penn-Sheraton Hotel on September 26–29

In the heart of downtown Pittsburgh, the Penn-Sheraton Hotel—site of the 1960 National Fall Meeting—faces Mellon Square Park and is flanked by the Alcoa Building to the left

One of the AWS groups pauses for a Honolulu welcome before emplaning to Kauai. After arrival, the groups assembled at a reception before setting forth on tours and Conference meetings

Some 58 members and their wives pose before the scenic background of the Kauai Inn prior to starting a boat trip up the beautiful Wailau River to the Fern Grotto

AWS Mid-Pacific Conference Held in Scenic Hawaii

The AWS Mid-Pacific Conference held in Honolulu following the Annual Meeting and Welding Exposition in Los Angeles April 25–29, was an unqualified success. Technical meetings, plant tours, assistance to the group forming an AWS Hawaii Section, social events, Hawaiian hospitality, informality, gay entertainment, unmatched climate, food and scenery all combined to provide experiences acclaimed by each of the 80 AWS members and their ladies representing every section of the mainland. These were joined at the technical meetings by many representatives of the welding industry in Hawaii.

During Saturday morning, April 30th, United DC-8 and Pan American 707 jet planes sped 70 members of the group from Los Angeles to Honolulu where they were joined by a few others and continued on Hawaiian Airlines to the island of Kauai and the lovely inn of the same name at Lihue. The accompanying photograph shows the smaller group that arrived in Honolulu via Pan American. A welcome-to-Hawaii cocktail party and dinner followed by an evening of native entertainment set the informal, friendly atmosphere which continued throughout the conference.

The schedule for the following day included a trip to Hanalei viewing the fabulous beauty of this "Garden Isle of Kauai" and, after lunch, a boat trip up the beautiful Wailau River to the exotic Fern Grotto. The second photograph shows some fifty-eight members of the group at Kauai Inn prior to departure on the boat trip. Many members will recognize Past President Humberstone, 1960–61 President Thomas, Vice Presidents Blankenbuehler and Chouinard, RWMA President Carrigan, your Secretary, and their wives. Names of others participating in the conference (some not in this picture) include Bailey, Bianco, Bowers, Buhler, Christensen, Crawford, Dunne, Earlbeck, Engquist, Forkner, Grace, Greene, Hinds, Hirsch, C. A. and J. S. Jung, Kerr, Knight, Long, Lutz, Monroe, Neary, Peterson, Profughi, Qualls, Raimy, Sauer, Seeland, Starner, Styer, Tepley, Wakely and Williams.

The group returned to Oahu and the Hawaiian Village Hotel in Honolulu to welcome new arrivals from the mainland on Monday with a reception followed by dinner on a catamaran sailing past famed Diamond Head and Waikiki beaches as the sun set and a nearly full moon joined the lights of the city in casting dancing reflections on the peaceful, rolling waves.

Tuesday morning all AWS members joined men of Hawaii interested in welded fabrication as J. F. Stacy, Chairman of the AWS Hawaii Section Activation Committee, convened the Mid-Pacific Conference and Professor Johnston of the University of Hawaii extended a gracious welcome to which President elect R. D. Thomas, Jr., responded. T. J. Crawford, Consulting Engineer, competently moderated a panel discussion on "Welding Processes" which included short talks by L. C. Monroe of *Welders' Digest*, Consulting Engineer C. M. Styer, Welding Supply Dealer A. E. Earlbeck, Hobart Engineer J. H. Blankenbuehler, Arcos President R. D. Thomas, Jr., A. F. Chouinard of Chemetron's National Cylinder Gas Division and Airco Vice President J. H. Humberstone. W. H. Carrigan of Kirkhof Manufacturing Corp. and many others participated in the lively discussion which continued the meeting past the scheduled closing time and permitted only a brief lunch period before departure on an inspection tour of the welding shops at Pearl Harbor.

Here the group was welcomed by W. L. Ramsay, J. E. Watson and W. D. Bennett, and then was conducted on an interesting tour through various shops where many cutting and welding operations were being used in both repair and new construction of complicated metal assemblies, including a large proportion made of aluminum, stainless steel and other special metals and alloys. The museum provided many instructive models and actual examples of special purpose naval vessels and other assemblies.

Wednesday morning AWS members and local representatives attended another technical session at which Secretary Fred L. Plummer discussed SOCIETY aims, projects and plans, covering international, national and especially local Section activities. He discussed the WELDING JOURNAL; WELDING HANDBOOK; Technical Manuals, Codes and Standards; educational training and guidance in High Schools, Vocational Schools, "in-plant" and "apprentice," in colleges and through special courses conducted by AWS Sections and the AWS School of Welding Technology; information and publicity services; expositions and national technical meetings; International Institute of Welding; the new

national headquarters and other items.

Following this presentation Vice President-elect J. H. Blankenbuehler, who presided throughout this session, introduced President-elect R. D. Thomas, Jr. who gave an excellent, well-illustrated talk describing "Some Dramatic Applications of Stainless and Low-Alloy Steel Welding." This evoked spirited discussion and many pertinent questions, forming an appropriate background for the afternoon inspection of the Oahu Sugar Company Mills.

The group, including some of the ladies, was met by Robert Laurance of Gaspro, Ltd., and introduced to Mill Superintendent John Vorfeld and Plantation Maintenance Superintendent Thomas Goskirk who gave personally conducted tours showing the progress of cane from the fields through washing, cutting, pressing, filtering, purifying, evaporating and centrifuging processes which produce the raw sugar; describing the stainless steel and other special metal equipment; and illustrating maintenance welding operations including an interesting build-up of large shafts with stainless-steel metal deposited by the inert-gas metal-arc process.

Following the conclusion of the formal Mid-Pacific Conference, the group enjoyed in succession: (1) a gay evening at a Japanese tea house where all discarded shoes, donned kimonas, sampled sake, ate, sitting on the floor at low tables, a traditional Japanese dinner with chopsticks and enjoyed native Japanese entertainment spiced with some Hawaiian and AWS talent; (2) a tour of Pearl Harbor on a large catamaran where the famed raid of Dec. 7, 1941, was reviewed and the U.S.S. *Arizona Memorial* was visited; a traditional luau at the beautiful Queen's Surf Club where rum punch, roast pig, native fruits and a full evening of excellent Hawaiian and Tahitian entertainment were presented in a lovely garden with ideal weather; a trip to windward Oahu past Diamond Head and Koko Head to Kalama Park for superb surf bathing followed by a barbecued steak dinner and another evening of informal native and AWS talent entertainment; and finally on Saturday, May 7th, cocktails and an Aloha buffet in the Hawaiian Village Hotel preceding the presentation of leis and alohas to the 50 members returning to various West Coast cities that night.

Several members stayed in Hawaii to visit the islands of Maui and Hawaii or to continue their visit in Honolulu. Enjoyment of all was increased by the efficient handling of arrangements by "Chuck" Coleman and Frank Kelly, and by the friendly reception and talented entertainment of "Ethel" and "Moki," representing Holiday House Travel Center, Inc.

On Wednesday evening, May 11th, Secretary Plummer, C. Styer of Seattle and G. L. Tepley of Chattanooga attended and spoke at the organization meeting for the proposed AWS Hawaii Section, held in an auditorium of the Hawaiian Electric Co. Temporary officers include Chairman J. F. Stacy of Gaspro, Ltd., Treasurer J. E. Horner of Honolulu Iron Works and Secretary L. P. Pauls of the Board of Harbor Commissioners. Section by-laws have been prepared and meetings were planned for June 15th, with a talk covering the Los Angeles Welding Exposition, and for July 20th. J. T. Lee is handling publicity. Several individuals are assisting the drive for new members. All AWS members who plan to visit Hawaii are urged to notify Secretary Plummer or contact J. F. Stacy, Gaspro, Ltd., 2305–2371 Dillingham Blvd., Honolulu 17, Hawaii, if they are willing to consider the possibility of meeting and talking with this new AWS group about welding problems.

Plans are being made to hold a reunion in New York next April at which some of the hundreds of color transparencies taken during the visit may be shown. Brilliantly colored shirts, slacks and muumuus will be combined with sweetly-scented flower leis, blue skies, rolling surf and superb scenery in providing a colorful background for action shots.

Fred L. Plummer

An Important Reminder

AUTHORS...

August 15th is the deadline when application forms and abstracts must be postmarked in order to receive consideration for presentation at the 42nd Annual Meeting to be held in New York, Apr. 17–21, 1961.

The application form was included as a detachable insert in the May issue of the WELDING JOURNAL. Additional copies of the application as well as "Instructions and Suggestions for Authors" may be obtained by writing to AWS headquarters, 33 W. 39th St., New York 18, N. Y.

AWS DIRECTORS-AT-LARGE

Term Expires	1961	1962	1963
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	D. B. Howard	F. G. Singleton	John Mikulak
	J. L. York	C. B. Smith	E. F. Nippes
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AWS PAST-PRESIDENT DIRECTORS

C. I. MacGuffie G. O. Hoglund

KEEPING YOU POSTED

by Fred L. Plummer

● President C. I. MacGuffie met with the San Francisco, Santa Clara, San Diego, Salt Lake City and Long Beach Sections during the five evenings, April 18–22, of the week preceding the Annual Meeting and Welding Exposition in Los Angeles. Your Secretary flew by jet plane from New York to Los Angeles on April 22nd to join President MacGuffie, Director McGinley and Past President Sander for the meeting of the Long Beach Section at which Dr. D. C. Smith presented the technical talk after President MacGuffie discussed SOCIETY aims and projects.

● Chairman R. H. Hogate, Vice Chairman G. Garfield and Program Chairman W. T. DeRouchey conducted the meeting which was attended by Past Director C. Breese, O. B. Bowers and many other Section members. W. C. Smithey and a group of members from Orange County met with President MacGuffie, Director McGinley and your Secretary to plan the organization of an Orange County Section of AWS. It is hoped to have this organization ready for authorization at the June 2nd meeting of the Board of Directors.

● A luncheon on Sunday, April 24th, for Chairman Sander and his Los Angeles Section Arrangement Committee Chairmen and their wives was the opening event of the AWS 1960 Annual Meeting and Welding Exposition, which was reported in the June issue of the WELDING JOURNAL. This was followed by a late afternoon reception for AWS National Officers given by the Los Angeles Section.

● ASME Vice President W. S. Heath and NWSA President A. S. Axtell with Mrs. Axtell officially represented their organizations and joined AWS officers in the receiving line at the President's Reception and at the banquet speakers' table. The program organized by the Los Angeles Section for the banquet was exceptionally good and seemed to please everyone.

● On Tuesday evening your Secretary and Mrs. Plummer entertained your National Officers and their wives at an informal dinner—one of the few times during the week when these men can relax for a short time from the full schedule of committee, council and board meetings and special events which keep them almost continually occupied.

● President MacGuffie presented his annual address and the many SOCIETY awards at the opening session, presided at the opening of the Exposition, at the all day meeting of the Board of Directors and at the open and closed meetings of the 1960–61 National Nominating Committee, attended meetings of the Technical and District Councils, WRC, Exposition, Membership, District Officers and other groups, participated in the President's Reception and spoke at the Banquet.

● President-elect R. D. Thomas, Jr., fighting a severe and stubborn virus infection which required the combined benefits of a skilled physician and a full assortment of modern wonder drugs to permit his attendance at the meetings, filled an equally strenuous schedule including his "acceptance speech" at the opening session, the receiving line at the reception in his honor, cutting the chain to formally open the Exposition, presiding at the meeting of the Technical Council, attending meetings of WRC, the Board of Directors and many other groups.

● Vice President A. F. Chouinard presided at the District's Council and Section Officers meetings and participated in most of the events and meetings just mentioned.

● Past Presidents J. J. Chyle and G. O. Hoglund, Treasurer H. E. Rockefeller and Convention Chairman J. E. Dato were active throughout the week and took part in many of these events. Exposition Committee Chairman J. E. Norcross presided at the meeting of that group and also, in the absence of Chairman T. S. Long, at a meeting of the Manufacturers' Committee.

● Vice Presidents-elect J. H. Blankenbuehler and C. E. Jackson as well as most of the newly elected Directors attended meetings of the Councils and Board of Directors on which they will serve during the 1960–61 fiscal year.

● Staff Members Fenton, Krisman, Phillips, Mooney, Rossi and Talento worked effectively to insure that all activities were completed on schedule and with maximum benefits to all those who were able to participate.

● Exposition Manager R. T. Kenworthy and his associates again demonstrated their fine abilities

PLANT TOUR GROUP VISITS U.S.S. WESTERN DIVISION

One of the interesting plant tours held during the 41st Annual Meeting at Los Angeles was at the extensive Consolidated Western Division of U. S. Steel Corp. Here a group witnesses a test demonstration on a missile chamber

in handling the record-breaking welding exposition.

● All chairmen of the Los Angeles arrangement committees performed outstanding jobs. More than 160 ladies registered and attended all or part of the excellent series of events included in their program.

● WRC Director (as of June 1, 1960) Ken Koopman and Chairman A. R. Lytle presided at the annual dinner meeting of the University Research Committee at which Professor A. E. Flanigan of the University of California was the principal speaker. AWS officers MacGuffie, Thomas and your Secretary attended this important conference.

● Following the Los Angeles events, Convention Manager Frank Mooney flew to Dallas to complete preliminary arrangements for the 1961 Fall Meeting and then to Pittsburgh to meet with hotel and convention bureau representatives to complete final plans for the 1960 Fall Meeting in Hotel Penn-Sheraton, September 26–29.

● During the week following the annual meeting, the successful AWS Mid-Pacific Conference was held in Honolulu. On May 11th your Secretary attended the organization meeting of a group planning the formation of an AWS Hawaii Section. These events are covered in a separate report in this issue of the JOURNAL. Two 4½-hr jet-plane flights with a short stop in Los Angeles brought your Secretary and Mrs. Plummer back to New York on May 15th.

● President-elect R. D. Thomas, Jr., attended the annual symposium of the AWS Cleveland Section on May 13th, speaking before the 500 members and guests who attended the dinner meeting following an afternoon of technical talks.

● On May 17th WRC and AWS friends held a surprise luncheon for W. Spraragen at which he was presented a certificate of appreciation and other gifts by WRC Chairman E. E. Michaels, Past Chairman Walter Green and Director Ken Koopman with Past Chairman A. B. Kinzel serving as master of ceremonies and reading messages from several industry leaders who could not be present. President C. I. MacGuffie spoke briefly on behalf of AWS. Staff members Mooney, Rossi and your Secretary attended this luncheon at the Engineers' Club.

● On May 20th WRC staff members held an informal tea and birthday party for Mr. and Mrs. Spraragen in the PVRC office, marking the official retirement of Mr. Spraragen on his sixty-fifth birthday. This event was reported in the May issue of the JOURNAL, together with statements concerning the remarkable record of accomplishments of Mr. Spraragen.

● On May 18–19 PVRC Material, Design and Fabrication Divisions and Executive Committee held meetings under the direction of Chairman I. E. Boberg, WRC Director Ken Koopman, WRC Secretary C. F. Larson and the three division chairmen.

● Visitors at headquarters during this week included Chairman Harry Landis of the New York Section, Director-elect Roy McCauley of Ohio State University and Si Greenberg, former AWS Technical Secretary, who announced that he was no longer associated with the Eutectic Welding Alloys Corp.

● On May 21st the AWS Philadelphia Section held a reception in honor of President-elect and Mrs. R. D. Thomas, Jr., at the Germantown Cricket Club. The reception was held in conjunction with the Annual Dinner Dance of the Section with Chairman F. P. Iapalucci, Chairman-elect W. H. Wooding and other Section officers and their wives, all in summer formal dress, joining Director E. E. Goehringer and his wife, the Thomases, Mrs. Plummer and your Secretary in a receiving line and at the speakers' table in a beautifully decorated banquet hall. Gifts were distributed to all the ladies following a brief program. Dancing continued until after midnight.

Following the close of the current

UNITED ENGINEERING CENTER FACT SHEET

Location:	United Nations Plaza, First Ave., between 47th and 48th Sts., New York City.
Size:	Twenty stories, 283 ft high, gross floor space 260,000 sq ft.
Appearance:	A slim tower faced with stainless steel, glass and limestone rising from a 2 story base of glass and stone.
Schedule:	Ground broken, Oct. 1, 1960. Foundations and basement completed April 1961. Completion estimated for middle 1961.
Purpose:	Headquarters for 18 American engineering societies.
Facilities:	Office space, meeting rooms for 400 persons, plus smaller conference rooms, modern library facilities. Exhibit area of 6235 sq ft and a cafeteria to seat 350.
Estimated Cost:	Approximately $12,560,000.
Financing:	By gifts from individual society members, industry and by the contemplated sale of the present building.
Fund Status:	The amount on hand or pledged is about $1½ million short of goal.

CONTRIBUTE NOW TO THE NEW HOME OF AWS

In consideration of the gifts of others I intend to give to

UNITED ENGINEERING CENTER BUILDING FUND

_____ Dollars $_____

Paid herewith $_____ Balance will be paid as follows

_____

Credit my gift to:

☐ AWS ☐ _____

Signed _____

Print Name _____

Address _____

fiscal year on May 31st, your 1960–61 Executive and Finance Committee will meet on June 1st and your New Board of Directors on June 2nd to adopt budget, appoint committee members and determine plans for the next fiscal year.

On June 4th President R. D. Thomas, Jr., and your Secretary will fly to London for conferences with British Welding Research Association Director R. Weck, British Welding Institute President E. Seymour-Semper and International Institute of Welding Secretary General G. Parsloe, before proceeding to Liege, Belgium, for the Annual Assembly of IIW at which your Secretary will become a Vice President of this 27-nation group.

Chicago Section Awards Scholarship Prizes

Two scholarship prizes of $500 each were awarded to high school students by the Chicago Section of AWS for outstanding exhibits at the annual Chicago Science Fair held April 7–10. One cash award went to Paul Leif, 17, of the Lane Technical High School, for his "Hydrospace," an underwater device for measuring temperature, pressure and radiation. The other award was given to Thomas Keys, 17, of Hirsch High School for his "Magnetohydrodynamic Generator" by which he explained the nature of the welding arc.

The purpose of the awards is to emphasize the importance of welding in modern technology and to promote the study of welding engineering.

Thomas Keys, Hirsch High School Junior, receives $500 cash award from Harry Schwartzbart of the Chicago Section

Paul Leif, Lane High Junior, is another $500 winner of the Science Contest sponsored by the Chicago Section

May 10, 1960

Gentlemen:

Naturally I was surprised and somewhat shocked at the elaborate write-up that an ordinary individual such as myself received in the May WELDING JOURNAL. *I want to thank you all for the wonderful things you said about me. I hope that they were partially deserved at least. I also am grateful for the nice things said about me by my Chief, Mr. Michaels, and by my friend, Mr. Plummer.*

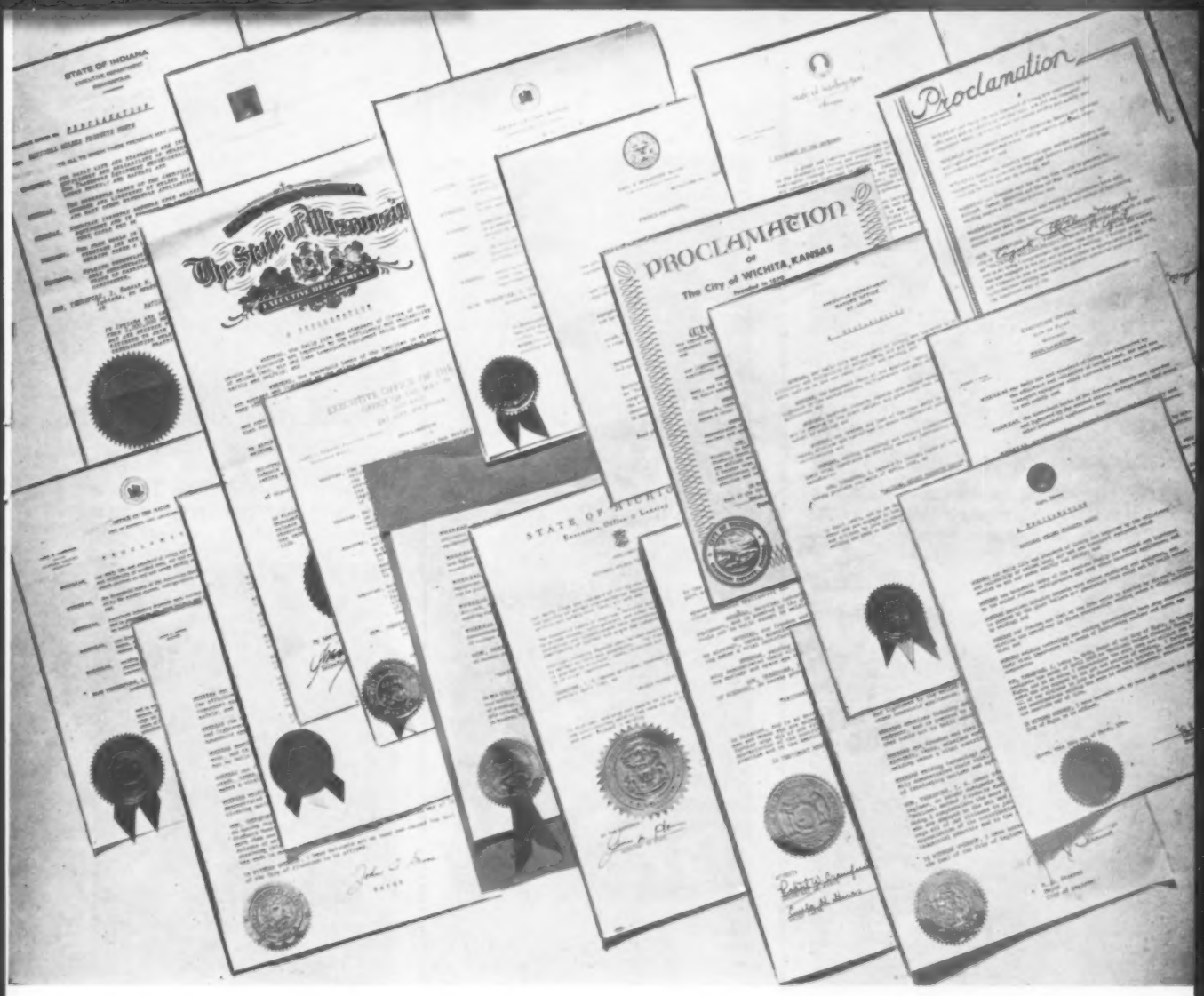
The tasks I undertook in the AMERICAN WELDING SOCIETY *and the Welding Research Council I enjoyed. Now that I will retire in a few short days, I want to express my appreciation to those who were willing to give me the opportunity to undertake these tasks. It is the leaders of these organizations, not I, who deserve the credit. They were the ones that backed their faith with the risk of money and prestige. If there have been successes in these enterprises, you can rest assured that such successes represent the work of many individuals.*

I retire with the knowledge that both the SOCIETY *and the Council will reach new heights of attainment.*

Very sincerely yours,
W. SPRARAGEN

AWS BRIDGE COMMITTEE MEETS IN CALIFORNIA

Members and guests of the AWS Conference Committee on Welded Bridges shown in session during their first West Coast meeting, held in Sacramento, Calif., April 19–20. The group spent the following two days inspecting fabricating shops in the San Francisco Bay area. Seated 6th, 7th and 9th from the left, respectively, are AWS Technical Secretary Ed Fenton serving as secretary; Bethlehem Steel Co.'s W. H. Jameson, chairman; and J. L. Beaton of California's Division of Highways who handled arrangements



The Nation Salutes Welding as AWS Spreads "National Welded Products Month" Across the Country

Amid the signing of dozens of proclamations by state governors and mayors of cities, towns and villages across the country, the month of April saw many demonstrations in a nation-wide salute to welding. Initiated by presidential proclamation in 1959, the month of April has become National Welded Products Month in recognition of the fast-growing billion-dollar industry. Many alert AWS sections took advantage of this event to proclaim to the public the part that welding plays in our national economy and in our everyday home life.

The following pages tell part of the story of the many activities conducted by AWS members during this national emphasis month. Supplementing this presentation, numerous special meetings, dinners, speakers, plant tours, open-house invitations and store-window displays have been reported with regular section news activities in previous issues of the WELDING JOURNAL. Not shown here, but equally important, are the many newspaper stories, radio and TV commercials, advertising copy and feature articles appearing in company publications.

How did it all add up? Members may gain an idea from the following pages of the overall impact resulting from their combined efforts. The sum total of these various activities amounted to an immense promotional drive for informing the public on the importance of welding in their daily lives—to make people aware that welding is synonomous with industrial progress.

CALIFORNIA

Eye-catching store-window display of ABSCO Welding Equipment and Supplies, Los Angeles, features National Welded Products Month

CONNECTICUT

Governor Ribicoff hands proclamation to N. Pompilio as (left to right) W. Johnson, B. Burba and W. Duncklee join ceremony

ILLINOIS

M. Ridloff, Mayor Monte of Elgin and J. J. Wolf, in the usual order, after signing document

Seated with Kankakee's Mayor E. Madison as he pens approval are Mrs. R. Pratt and K. Anger. Standing are R. Lincoln, J. J. Wolf and R. L. Barnet

With Mayor J. P. Henessey of Joliet are K. Hanks, A. Gerl and J. J. Wolf

INDIANA

H. W. Handley, Governor of Indiana, announces NWPM declaration to F. Stout, R. Hilburt, R. Martin, B. Canine, E. O. Smith and F. Watts

KANSAS

Receiving greeting and proclamation from Kansas Governor G. Docking, J. Finke is accompanied by J. Townsend, W. Smith, W. Dent and H. Nelson

Wichita joins the parade as Mayor Fugate announces NWPM before W. Dent, seated, and Joe Townsend, Jim Townsend and J. Finke

LOUISIANA

Shreveport's Commercial National Bank supports the program with this fine window display

MASSACHUSETTS

Governor F. Furcolo announces his proclamation before G. Hall, H. Udin, A. Barilaro, Rep. J. E. Brett and B. Goodrich

MICHIGAN

Fisher Body Assembly Line No. 1 at Flint adds a booster with B. J. Meader and F. Ray at the controls

MISSOURI

Governor J. F. Blair, Jr., puts his signature to the proclamation announcing NWPM

In the act of official recognition is Mayor R. B. Tucker of St. Louis. Standing are H. W. Castle, C. Burrow, A. Hauser, R. Elfrin, G. O. Bland and E. G. Mathae

OHIO

Emphasizing his AWS affiliation, Mayor W. Pestrak of Warren "tacks" the notice as E. Phelps, E. A. Craig, R. H. Foxhall assist

PENNSYLVANIA

Penning his signature under the gaze of L. Constantine is Allentown's Mayor J. T. Gross

WASHINGTON

Governor A. D. Rossellini approves the resolution in the presence of H. F. Knab and R. Eide

Symbolic of the occasion, Mayor B. Hanson presents the proclamation to R. L. Stein and E. E. Moe in the welding shop of Tacoma's Vocational High School

WISCONSIN

Governor G. A. Nelson approves the measure supporting NWPM, backed by N. A. Braton, R. A. Hart, M. Kern and F. E. Theiler

Appleton's Mayor C. Mitchell designates April for welding month at behest of R. Hart, M. Kern, A. Tucker, K. Loos and J. G. Waldron

Attractive window display at Appleton's First National Bank Building

When you see an eight-eyed spider...

call an *ARANEOLOGIST*

(specialist in spiders)

For details, circle No. 8 on Reader Information Card

when you've got welding problems... call in *LINCOLN*

(specialists in arc welding)

A SOUTHERN sheet metal fabricator had "burn-thru" in the welds. The LINCOLN Field Engineer recommended Fleetweld 37 and licked the "burn-thru" problem. But more important, the new electrodes increased welding speeds to such an extent that overall costs dropped a third.

And right there is a good reason for doing business with LINCOLN. Ideas to whip knotty production problems come naturally to the Field Engineers. They are factory-trained where they—and everyone else—gets paid according to his individual contribution to the company's goal—superior products and service to you at continually decreasing costs. So, while he knows welding, he also understands how to relate it to your total manufacturing operation.

That's why we say it's a good idea to do business with LINCOLN where arc welding is a specialty and cost reduction comes to you as a "plus" at no charge.

THE LINCOLN ELECTRIC COMPANY
Dept. 1550 • Cleveland 17, Ohio

LINCOLN ELECTRODES

For details, circle No. 8 on Reader Information Card

SECTION NEWS AND EVENTS

As reported to Catherine M. O'Leary

California

ELECTRODES

Los Angeles—D. C. Smith, chief metallurgist engaged in research and development of arc-welding electrodes and production quality control for the Harnischfeger Corp., was the speaker at the April 22nd meeting of the *Long Beach* Section. His talk was on "Iron-powder Manual Arc-welding Electrodes" and was accompanied by some excellent slides.

The members and guests also heard an address on "AWS Activities" by President C. I. MacGuffie.

Present at the meeting were Fred Plummer, national secretary, C. P. Sander, past president and F. McGinley, director of District 10.

ELECTRODES

Berkeley—On Monday evening, April 18, the *San Francisco* Section met for dinner and regular meeting at Spengers Fish Grotto in Berkeley.

Technical speaker was D. C. Smith, chief metallurgist, Electrode Division of the Harnischfeger Corp., Milwaukee. Through a good application of slides, Dr. Smith presented the subject of "New Developments in Welding Electrodes." He traced the development from pre-World War II to the present date, showing how recent developments in base materials has demanded new electrodes to give the required physical properties as well as heat-treating properties. Also pointed out was the increased deposition rates and reduced hydrogen content of recently developed welding electrodes. Basically, the increased deposition rate is associated with the increased iron-powder content of the electrode covering. The lower hydrogen content in the weld deposit is associated with the lime type of electrode covering.

President MacGuffie in his coffee talk gave a very good outline of the functions of the various offices at the New York headquarters. He also presented some background information leading up to the decision of the SOCIETY to associate with others to support the building of the new Engineering Center in New York, where headquarters offices will be located. The history and growth of the SOCIETY, as presented by Mr. MacGuffie, were impressive and indicate great things for the future.

ELECTRODES

San Jose—The *Santa Clara Valley* Section members enjoyed the fellowship hour before the dinner meeting on April 19th at the Hawaiian Gardens in San Jose, and were happy to have the opportunity to meet President MacGuffie. Old acquaintanceships were renewed by many of the members with Mr. MacGuffie.

As coffee speaker, Mr. MacGuffie gave a brief résumé of the various activities carried on at the home office in New York. He left the message with the Section "that the prime duty of the SOCIETY was to get the work about welding to the youth of today, because the welding industry of tomorrow depends upon them."

Technical speaker was D. C.

ATTENTION SECTION SECRETARIES:

Notices for November 1960 meetings must reach JOURNAL office prior to August 20th so that they may be published in the October Section Meeting Calendar. Please give full information concerning time, place, topic and speaker for each meeting.

PRINCIPALS AT MEETING OF LONG BEACH SECTION

Iron-powder electrodes were discussed by D. C. Smith at the April 22nd meeting of Long Beach Section. Left to right, above, are F. McGinley, National Secretary F. L. Plummer, President C. I. MacGuffie, Section Chairman R. H. Hogate, Dr. Smith, Past-president C. P. Sander and W. T. DeRouchey

President MacGuffie, center, who spoke on AWS activities, is shown receiving a guest-speaker award from Chairman Hogate. Secretary Plummer looks on

Smith, chief metallurgist, Electrode Division, Harnischfeger Corp., Milwaukee, whose subject was "Electrodes for Manual Arc Welding." Dr. Smith's lecture covered the field of welding electrodes for manual arc welding of steels in general. He discussed the history of the various electrode coverings now in use and the functions that each type is designed to fulfill.

The fact that welding has now developed from the stage of being a "trick" or an "art" into a science and tool for industry's use for obtaining desired results, was impressed on the minds of the audience.

SANTA CLARA VALLEY SPEAKERS

At the April 19th meeting of Santa Clara Valley Section, President C. I. MacGuffie spoke on the activities carried on by AWS headquarters

The technical speaker of the evening was D. C. Smith. His talk dealt with electrodes for manual arc welding

Colorado

ARC CUTTING

Denver—The last meeting of the 1959–60 season of the *Colorado* Section was held on May 10th at Cavaleri's Restaurant. After a good dinner, the speaker for the evening, Jerry McEvilly of Lancaster, Ohio, presented his talk on "The Carbon-arc Compressed-air Process" using slides to illustrate his points. This was a most interesting presentation, entirely different from any other subject presented this season.

Ralph Bunker of the Humble Oil Co. was the coffee speaker. He is a member of the Denver Junior Chamber of Commerce and gave a talk on the Better Business Bureau—and what it does for you. This was very interesting.

The following officers were installed for the coming year: Chairman, Paul J. Foehl; Vice Chairman, Sam Flohr; 2nd Vice Chairman, Walter L. Bush; Secretary-Treasurer, C. E. Reissig; Executive Committee—John R. Mascarello, E. E. Lambercht, H. B. Klodt, E. Roy Lindberg, David C. Card and E. W. Weinberger; Membership Chairman, William O. Brown.

Connecticut

WELDING PROCESSES

Bridgeport—D. R. Kelker of the Air Reduction Co., Union, N. J., was the speaker at the April 21st meeting of the *Bridgeport* Section held at the Fairway Restaurant. The title of his talk was "Developments in Welding Processes and Tooling."

Mr. Kelker opened his talk by comparing present-day tooling with thirty years ago when the average machine shop had only three basic tools. New metals are demanding much better tooling. He also reviewed the present methods of welding and touched on the newer processes such as plasma arc, etc. He then showed a film on "Aircomatic Welding and Cutting."

ELECTRON-BEAM WELDING

Glastonbury—The *Hartford* Section held its regular monthly meeting on April 19th at the Villa Maria Restaurant in Glastonbury.

Chairman W. A. Duncklee com-

SAN FRANCISCO HEARS MacGUFFIE AND SMITH

President C. I. MacGuffie and D. C. Smith were the main speakers at the April 18th meeting of San Francisco Section. Seated at the head table are, left to right, W. Ajello, B. Faas, President MacGuffie, Dr. Smith, Section Chairman R. E. McCormick, K. Freitag, G. Flumerfelt and C. B. Robinson

President MacGuffie addressing the meeting on AWS activities, while Dr. Smith listens attentively. The technical speaker's subject was the development of welding electrodes

J. A. K. SPEAKER

Jerry McEvilly was the principal speaker at the May 12th meeting of J. A. K. Section. His subject dealt with carbon-arc compressed-air cutting process

plimented the committee on the success of the National Welded Products Month campaign. Through the committee's strenuous efforts, 300 posters and 5000 handbills were distributed. Governor Ribicoff issued a proclamation, with members and news photographers present, and three local TV stations promoted Welded Products Month during their station breaks.

Technical speaker at this meeting was William Farrell of Sciaky Bros., Inc. He presented a very informative talk on "Electron-beam Welding."

Florida

STUD WELDING

Miami—The April meeting of the *South Florida* Section was held on the 20th at the Miami Pioneer Club.

A brief business meeting preceded the technical meeting.

Two speakers were scheduled for the technical meeting: Bob McCahn and Tom Harris, affiliated with the Gregory Industries, Clearwater, Fla. Their presentation on stud welding was accompanied by the showing of slides and live demonstrations.

Illinois

SUBMERGED-ARC WELDING

Danville—The *Eastern Illionois*

AT PEKIN SCIENCE FAIR

D. Hawes, H. Smith and W. Callaway, officers of the Peoria Section, are shown presenting Miss Jody Buchanan a Scotty-dog footscraper at Pekin Science Fair

Section met on April 27th at Connor's Restaurant in Danville for dinner and meeting.

Speaker for the evening was C. A. Heffernon of Linde Co., Chicago. He explained the basic principles and components of the submerged-arc process, power supplies used, control mechanisms, applications and limitations.

ARC CUTTING

Aurora—An interesting lecture, accompanied by slides, was given by Jerry McEvilly of the Arcair Co., Lancaster, Ohio, at the May 12th meeting of the *J. A. K.* Section held at Harmony House in Aurora.

Election of officers was announced as follows: Chairman, Robert Lincoln; 1st Vice Chairman, Robert Barnet; 2nd Vice Chairman, Pete Vanderploeg; Secretary, Ken Hanks; Treasurer, Len Nielsen; Directors—Joe Ruptic, John Limacher, August Chopp, R. Anderson, Bill Lane, Chas. Alexander; Membership Chairman, Robert Barnet; Advisory Committee—John J. Wolf, Tony Gerl; Technical Chairman, John J. Wolf; Publicity Chairman, Chas. Stamm.

SCIENCE FAIR

Pekin—The *Peoria* Section participated in the recent Pekin Science Fair with working displays of oxygen cutting of Scotty dog footscrapers, arc welding of names on the scrapers, a liquid-oxygen demonstration of subzero temperatures, an inert-gas metal-arc welding machine for aluminum and a question box for written inquiries concerning welding.

The Section had a similar display at the Peoria Science Fair.

ACRO WELDER MFG. CO.
MILWAUKEE
WELDING ENGINEERS
MACHINERY BUILDERS
ESTABLISHED 1936

ACRO® general purpose spot-projection-butt-seam resistance welding machines.

ACRO-ARC® special purpose production welding machinery employing automatic arc welding processes.

ACROMATIC® special purpose production welding machinery employing resistance welding processes.

ACRO-MAGNETIC® magnetic force spot, projection, and percussion welding machines.

For details, circle No. 9 on Reader Information Card

Indiana

DINNER DANCE

Indianapolis—A Ladies' Night Dinner Dance was held on April 22nd in the Rainbow Room of the Severin Hotel by the *Indiana* Section. Cocktail hour preceded the dinner which started at 7:30 P.M. for 55 members and guests and was followed by a drawing for five door prizes. From 9 P.M. to 12 midnight, there was dancing to the music of Chuck Baldwin's orchestra.

The dance was not formal and a very enjoyable time was had by all.

STAINLESS STEELS

South Bend—R. H. Espy, research engineer for the Armco Steel Corp., Baltimore, gave the *Michiana* Section a very interesting talk on the precipitation-hardening steels and their weldability, at the April 21st meeting held at Russ Restaurant.

At first glance, Mr. Espy said, the analyses of the PH steels present what appears to be a most unscientific hodge-podge of compositions. But actually, the analyses produce three types of alloys. These are called martensitic, semiaustenitic and full austenitic, as determined by the structure obtained from the high-temperature heat treatment.

The proper balance of composition in both base metal and filler metals is extremely important because one condition often encountered in these alloys at the high temperatures used in welding is a coarse grain size with stringers of ferrite (delta iron) which reduce strength and ductility of weldments. To reduce this possibility to a minimum, at the present state of the art, it is recommended that weldments be given an annealing treatment and an overaging treatment. While this reduces the strength below that possible to obtain in the base metal, the increase in ductility is felt to merit the loss.

Because most of these alloys contain aluminum, the inert-gas-shielded arc method is the only suitable one for fusion welding and even that is not recommended for austenitic alloys. Resistance welding is the better process for them. Flash welding, however, is not recommended for the semiaustenitic alloys.

USE
READER INFORMATION CARD

Iowa

OXYGEN CUTTING

Des Moines—The regular monthly meeting of the *Iowa* Section was held in the Garden Room of the Hotel Kirkwood on April 21st. An excellent buffet dinner was enjoyed by 49 members and guests.

Speaker for the evening was Henry Hasse of the Victor Equipment Co., Chicago. Mr. Hasse gave a short talk on "Oxygen Cutting." He had with him a report from a study conducted by his company on the merits of natural gas versus oxyacetylene for cutting purposes.

The meeting was adjourned to the Pittsburgh-Des Moines Steel Co., where Mr. Hasse proceeded to give a live demonstration of oxygen cutting using a new torch that has been developed to use either natural or oxyacetylene gas. The demonstration was well received and proved of interest to many.

Kansas

AUTOMATIC WELDING

Wichita—The *Wichita* Section heard an informative talk on "Automatic Welding Machinery" at their meeting on March 14th held at the Stockyards Hotel. The talk was given by Anthony K. Pandjiris, president of the Pandjiris Weldment Co., St. Louis, Mo.

The talk was accompanied by a series of slides depicting various automatic welding machinery.

Maryland

ANNUAL DINNER DANCE

Baltimore—The fifth annual dinner dance of the *Maryland* Section was held on May 7th at the Southern Hotel in Baltimore.

A cocktail hour preceded a most delicious dinner which was attended by 202 members, wives and guests.

Following the dinner, Frank Jones was presented with his past chairman's pin, and the officers for the 1960–61 season were announced as follows: Chairman, Richard Metius; 1st Vice Chairman, John Benson; 2nd Vice Chairman, Robert Miles; Secretary, Kermit Sanders; Treasurer, Virdis Miller; Directors-elect —Wilson Rohde, Fred Kreppel and Harry Espy.

Again this year, group singing of old and new songs was led by the

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Industrial Arc Welder

Has patented dual-coil transformer with balanced electrical circuit • Promotes smooth, steady arc under all welding conditions • Glass insulated windings add to transformer life • Rigidly, permanently mounted chatter-free shunt • Single inch of shunt travel adjusts for entire output current range • Write for data sheet that tells you more.

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WELDING PROGRESS REVIEWED IN ST. LOUIS

The April 14th meeting of the St. Louis Section was featured by a talk by Harry Schwartzbart on the history of welding. Also shown were numerous displays proclaiming April as "National Welded Products Month." As shown above, a large crowd was on hand

wandering accordionist, and numerous door prizes were given to the ladies holding the lucky numbers.

Following this part of the program, the floor was cleared and the remainder of the evening was spent dancing to the music of the "Diplomats."

All present agreed it was a truly enjoyable affair.

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Yes, the swing is on and here's why:
● 30% More Heat Resistant than any other make.
● Brilliant Red and Yellow Glass Fibre Colors insures identification of Holder anywhere in plant—Valuable Safety Feature.
● Low initial cost, easy and economical to maintain.
Sold only through Welding Supply Distributors throughout the U.S. and Canada.
LENCO, Inc.
JACKSON, MISSOURI
Weld with HI-AMP
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Missouri

AUTOMATION

St. Louis—An unusual and excellent meeting of the *St. Louis* Section was held on May 12th at Ruggeri's Restaurant. The meeting opened with the usual time devoted to "fellowship" and then a buffet supper was served, followed by dinner at which 95 were present, with 10 arriving later.

Also included in the attendance were 15 past chairmen of the Section. This was their night. Each was introduced by the master of ceremonies, and each had a few words to say.

Installation of officers for the coming year followed. The new chairman is Ned Nyberg, Aronson Machine Co.

Master of ceremonies for the evening was Bill Noonan with Merrill, Lynch, Pierce, Fenner & Smith, and finalist in Toastmaster's Club contest.

Jim Brown, chief welding engineer, Allis Chalmers Manufacturing Co., Springfield, Ill., gave an up-to-the-minute review of welding and automation. He showed outstanding examples of improved products and dollars and cents savings.

WITH L. I. SECTION

R. Gallagher, left, introduces Nelson S. Stevens, the technical speaker at the May 12th meeting of Long Island Section

New York

INDUCTION HEATING

Bellmore—The *Long Island* Section met on May 12th at Sunrise Village for dinner and meeting.

Featured speaker at the meeting was Nelson B. Stevens of the Eastern Welding Equipment Co., Inc., Westbury, N. Y. His talk, entitled "Induction Brazing, Heat Treating and Welding" was accompanied by slides and sound motion pictures. It covered the range of heating by induction for such applications as shrink fitting, upsetting, brazing and welding. Both high- and low-frequency apparatus were discussed. The greatest interest centered on inert-gas-shielded brazing and welding operations.

ANNUAL DINNER

New York—The *New York* Section climaxed their 1959–1960 season with a "bang" on Friday evening, May 6th. The occasion was the well-known Annual Dinner and social get-together of the section. There were a total of 165 enthusiastic members and guests present. Since the demise of Toots Shor's, this year's affair was held in the Grand Ballroom of the Cornish Arms Hotel on West 23rd Street. George Metterhauser was chairman of the com-

JOINING OF ALUMINUM

Shown discussing aluminum-joining problems at the April 29th meeting of the Carolina Section are, left to right, R. Cope, guest speaker Charles Brown and Section Chairman Tom Jenkins

mittee in charge of the arrangements and entertainment. A variety of table prizes were donated by the various local business groups and manufacturers in and around New York City.

During the early part of the festivities, Harry D. Landis, Jr., handed over the helm to M. D. "Dan" Bellware, his successor for the coming season. At this time, Mr. Landis was presented with his Past Chairman's Pin. Mr. Bellware explained to him that in the New York Section "old chairmen do not pass away," they just go back to work.

The following officers were elected to assist Chairman Bellware during the coming season: First Vice Chairman, A. V. Thoren; Second Vice Chairman, M. A. Feiner; Secretary, H. C. Phelps; Treasurer, E. N. Madison; Executive Committee—J.E. Mooney, R. T. Berg, D. C. Herrschaft, E. J. Luiton, C. M. Dick, D. B. Peterson, J. J. Giraldi, H. C. Cook, J. L. Cahill, C. H. Swan, H. F. Siep and T. Murray.

SPOT WELDING

Olean—The *Olean-Bradford* Section was privileged to have Joseph W. Kehoe of the Westinghouse Corp., East Pittsburgh, Pa., as guest speaker at their March 19th meeting held at The Castle in Olean. Mr. Kehoe was visiting in the dual capacity as speaker and as District Director.

Mr. Kehoe presented some very interesting facts and figures about the District and its activities. He also answered questions from the floor concerning the AWS structure.

In his presentation of "Inert-gas-shielded Metal-arc Spot Process," Mr. Kehoe demonstrated the uses and economies of this type of welding. His slides illustrated the actual jobs and the experiments from which the data were collected; it gave all present a good insight in the application of this welding process.

North Carolina

JOINING OF ALUMINUM

Charlotte—The regular monthly meeting of the *Carolina* Section was held on April 29th at Charlotte, N. C. The program for the evening was on "Joining of Aluminum and Aluminum Alloys." Charles Brown of the All-State Welding Alloys Co. was the guest speaker. After a movie which showed all of the basic techniques of joining aluminum and some of the inherent problems associated with aluminum, Mr. Brown gave a talk on brazing and soldering methods for thin sections of aluminum. He gave several interesting illustrations of practical solution to aluminum-joining problems.

The Southeastern Welding and Maintenance Seminar to be held in Raleigh, September 14–16, was discussed. Concurrently the Carolina Section will sponsor a four-day trade show at the North Carolina State Fair Arena to be called the "Southeastern Show."

Ohio

ANNUAL QUIZ

Dayton—Thirty-five members and guests of the *Dayton* Section enjoyed a roast beef dinner and social period prior to the Annual Quiz Program held at Kuntz's Cafe on Tuesday, May 10th.

The quiz was divided into four welding classifications: Gas, Resistance, Arc, and Gas Shielded.

The most points in all classifications were obtained by Bill Kolb, of Delco Products, who picked up the patio serving tray and by Bob Bowman, of WADC, who chose the barbecue set. A pair of patio torches went to Bob Hous, of Inland Manufacturing, for high man in the "gas" group. Tom Falter, of Frigidaire, and Bill Schober, of Hobart Bros., each received a Lawn Chair for their points in resistance and arc classifications. John Headapohl, of Hobart Bros., carried home an ice bucket for his points in the gas-shielded classification.

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M&T Murex Muretran* All-Purpose Welder

Most versatile welder ever developed • Instant changeover to manual, automatic, inert-gas spot, MIG and TIG welding • Unique plug-in timers for gas pre-flow, post-flow, high frequency drop-out, spot arc • Patented, dual coil windings in saturable shunt transformer • Sealed silicon rectifiers assure highest efficiency, long life • AC-DC or AC models • Write for data sheet.

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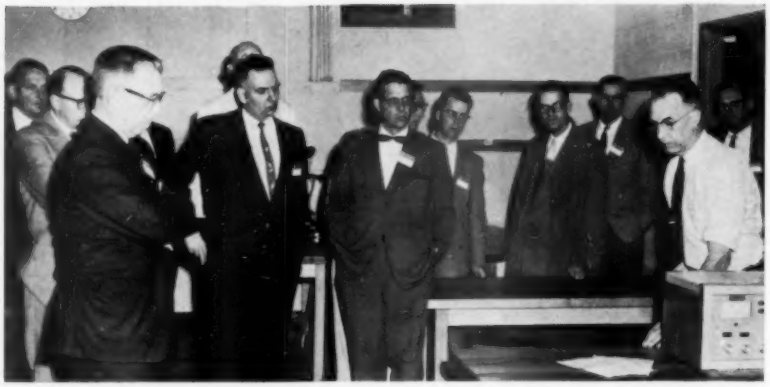
PLANT TOUR

Shippingport—A large turnout of over 150 members and guests was on hand for the *Mahoning Valley* Section's plant tour of the Duquesne Light and Power Co.'s Atomic Power Generating Station at Shippingport, Pa., on April 22nd.

Over three chartered bus loads were treated to an excellent trip through the atomic-power station and were shown all of the available facilities. These included a detailed description of the atomic reactor using a full-scale model, tour of the generating plant, reactor building and control room. Many questions were answered by the very hospitable personnel and the trip as a whole was one of the most successful programs undertaken by the Section.

In addition to bus transportation, there was a dinner served on the way down to the plant. Liquid refreshments were also available for everyone during the return trip. The executive committee was very pleased by this large attendance and the many favorable comments on the trip.

STUDENT AFFAIRS NIGHT AT OREGON STATE COLLEGE



Members of Portland Section visited Oregon State College on April 19th. Here the group listens to Dr. Ed Yunker explaining facilities of setup rooms in new Physics and Chemistry Building

Oregon

TOUR OF LABS

Corvallis—The *Portland* Section traveled to Corvallis on April 19th and held a joint meeting with the Oregon State College Student Chapter.

George B. Cox, head of the Department of Industrial Engineering and Industrial Arts, outlined and gave a brief history of the college course "Production Technology," which is designed to prepare man power for modern industry.

Later, the group was taken on a tour of the new Physics and Chemistry Building by Dr. Ed Yunker and Professor Daly, who briefed the members on the operation of a Nuclear Reactor. Prof. Asa Robley conducted a tour through the college's forging and welding laboratories.

no matter what the two metals are . . .

now you can **SOLDER** them

PROBLEM:
Joining copper pipes in extremely hard water area. Lead solders made porous joints. Heat required for high temperature solders burned copper pipes.

SOLUTION:
All-State's #430, a silver-bearing solder which flows at 430F, made perfect, permanent joints, solved the problem.

ALL-STATE has a solder for joining any commercial metal or alloy to any other . . . in one or more temperature ranges. For typical examples, see tables below:

400°F-500°F							700°F-800°F					
Al.	Copper	Brass	Steel	S.S.	Nickel		Al.	Copper	Brass	Steel	S.S.	Nickel
37	107	107	107	107	107	Aluminum	56	105	105	105	105	105
107	430	430	430	430	430	Copper	105	105	105	105	105	105
107	430	430	430	430	430	Brass	105	105	105	105	105	105
107	430	430	430	430	430	Steel	105	105	105	105	105	105
107	430	430	430	430	430	Stain. Steel	105	105	105	105	105	105
107	430	430	430	430	430	Nickel	105	105	105	105	105	105

Reference numbers above indicate All-State solder to be used for joining metals.

A set of four complete tables, covering temperature ranges from 400F to 800F, is yours for the asking. Send for free Instruction Manual, too.

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Pennsylvania

PLANT TOUR

Bradford—A fine group of members and guests of the *Olean-Bradford* Section gathered at the Holly Hotel in Bradford on May 17th. After a fine dinner and a short business meeting, the group adjourned to the Bovaird and Seyfang Plant.

At the plant, groups of seven were formed and taken on a very thorough tour of the Bovaird and Seyfang facilities. The groups were privileged to see the manufacturing and assembly of their line of skid-mounted gas-powered compressor units. Of special interest were their welding shop and the heat exchanger section.

SUBMERGED-ARC WELDING

Philadelphia — "Submerged-arc Welding of Low-alloy Steels" was the subject of an extremely

interesting discussion given by P. J. Rieppel, chief of the Metals Joining Research Division, Battelle Memorial Institute, at the April 18th meeting of the *Philadelphia* Section held at the Engineers Club.

Mr. Rieppel reviewed the developments that led to the production of submerged-arc welds having a minimum yield strength of 80,000 psi and Charpy V-notch bar values of over 30 ft-lb at 100° F.

He presented some very interesting data showing what can be obtained in the way of higher-physical values in welds by varying the ingredients used in the flux.

ELECTION OF OFFICERS

Philadelphia—The *Philadelphia* Section announced the results of their election for 1960–61 as follows: Chairman, Walter Wooding, Arcos Corp.; Vice Chairman, David Buerkel, A. O. Smith Corp.; Vice Chairman, Frank Hussey, Frankford Arsenal; Secretary, Albert Young, General Electric Co.; Treasurer, K. Wm. Ostrom, K. Wm. Ostrom Co. Inc.; Executive Board Members—Henry Stetina, Lorin Poole, Joseph Girine and George Koby.

23RD ANNUAL DINNER

Pittsburgh — The *Pittsburgh* Section held their Twenty-third Annual Dinner and Ladies' Night affair at the Webster Hall Hotel on Friday evening, April 29th. Section Chairman Paul Masters presided.

A cocktail party was held from 5:30 to 7:00 P.M., at which time dinners of lobster tail and prime ribs were served.

The highlight of the evening was the recognition and tribute paid to Joe Minnotte who retired as secretary of the Section after serving 30 years. He was presented with a plaque signed by the past chairmen with whom he had served. In addition, he was presented with a pair of opal cuff links.

The Starlets, talented young singers and dancers, entertained with a very pleasing and well balanced program.

The evening closed with the drawing for door prizes. The grand prize, a Hi-Fi Stereo, donated by Minnotte Brothers, was won by W. M. Rogerson.

This was a most successful affair with over 400 in attendance.

Tennessee

HARD SURFACING

Kingsport—The *Holston Valley* Section held its regular monthly dinner meeting on April 19th at Skoby's Restaurant in Kingsport.

Speaker of the evening was Ellis Harlow with Coast Metals. He spoke on "Hard Surfacing, Its Characteristics, Applications and Methods." Slides were used to illustrate the talk.

NEW OFFICERS

Kingsport—A new slate of officers for the *Holston Valley* Section was presented by Hugh Harr, Chairman of the Nominating Committee, at the April meeting, as follows: Chairman, C. W. Griffin, Enterprise

SPEAKS ON SUBMERGED-ARC WELDING

Submerged-arc welding of low-alloy steels was discussed by P. J. Rieppel at April 18th meeting of Philadelphia Section

Frank Hussey, left, and Walter Wooding have been elected Vice Chairman and Chairman, respectively, of the Section

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M&T Murex DC Rectifier Welder

Offers best type of rectifier for this service: non-aging silicon diodes—hermetically sealed • Assure long life, extremely dependable operation, as much as 98% efficiency • Machine designed for instant recovery voltage: arc easily struck, stabilized, maintained • Easy settings: simple selector and knob control for current range, polarity • Write for data sheet.

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HOLSTON VALLEY SPEAKER

On March 15th, the Holston Valley Section heard a talk by Wm. B. Sharav on the subject of new applications of submerged-arc welding

Wheel and Car Corp., Vice Chairman, Larry Long, Tennessee Eastman Corp.; Secretary-Treasurer, Larry Parsons, Tennessee Eastman Corp.; Directors—3 years, Jim Todd and Conley Scott; 1 more year to serve, J. Hackley and H. Suggs; 2 more years to serve, Van Bolling and B. Jourgenson.

PROCEDURES

Nashville—The May meeting of the *Nashville* Section was held at Kinnard's Restaurant on the evening of May 12th. A social hour was enjoyed by some 40 members and guests.

The principal speaker for the evening was R. B. Hoppe, who is acting chief of Experimental Tool Engineering Section of the Laboratory, which is one of the nine laboratories making up the development operations division of the Army Ballistic Missile Agency.

Dan Daley, who is a specialist on welding procedures, assisted Mr. Hoppe.

DISSIMILAR METALS

Knoxville—The *Northeast Tennessee* Section met on April 12th at Regas Restaurant in Knoxville. Twenty-five members attended the dinner and meeting. The speaker for the evening was L. M. Petryck, Development and Research Division, International Nickel Co., Inc., New York City.

Mr. Petryck's informative 60-minute talk on "The Welding of Dissimilar Metals" was supplemented by slides. His talk covered the electrodes, techniques and results associated with the joining of the various combinations of stainless steel, Monel, steel, Inconel and nickel.

Texas

METALLIZING

Houston—Sixty members of the *Houston* Section attended the dinner meeting held on April 20th at the Houston Engineering and Scientific Society. Joe Young of General Metallizing and Machine Co., spoke on the subject "Application of Metallizing to Industrial Equipment." His very interesting talk was accompanied by color slides.

Before dinner, a movie, "Holiday in Hawaii," was shown through the courtesy of Humble Oil and Refining Co.

VOCATIONAL EDUCATION

San Antonio—The *San Antonio* Section met on May 2nd at Cap'n Jim's with a turnout of 43 members and guests.

Chairman Bob Hamilton announced the results of the election of officers for 1960–61 as follows: Chairman, Fred W. Smith; First Vice Chairman, C. E. Hosier; Second Vice Chairman, A. J. Bell; Secretary, John E. Bergeron; Treasurer, E. E. Wagner; Directors—George R. Martin, W. J. Thornton, Francisco DeLeon, Elmer G. Heimer, David R. Smith and Gus C. Eschenburg.

Speaker of the evening was W. H. Wood, welding instructor at San Antonio Vocational and Technical High School, who discussed "What Is Vocational Education?" Mr. Wood gave an outline of the training received by the students, stating that they must be up in their academic subjects; also, if two or more academic subjects are failed, the student must drop his shop class.

It was interesting to note that the students in the vocational classes are enrolled in the Vocational Industrial Clubs, known as V.I.C. This organization was formed in 1947 by the educators of Texas. Chapters meet monthly. District and State meets are held annually in which Chapters compete with others.

Another interesting use of vocational facilities is that adult extension courses are available in the evenings.

Mr. Wood had test weld specimens on display made by the students.

The August meeting of the Section will be held on August 24th at the Lone Star Brazier Room. Past Director of District 9, Percy Pennybacker, will be the guest speaker.

TALKS ON HARD SURFACING

Section Vice Chairman C. Scott, left, and Chairman J. Myers, Jr., flank speaker Ellis Harlow at April 19th meeting of Holston Valley Section. Mr. Harlow spoke on hard surfacing

FABRICATION OF T-1 STEEL DISCUSSED

Pictured at the April 22nd meeting of Fox Valley Section are, left to right, G. H. Jacklin, J. Teigen, Niels C. Miller, Max Kern and guest speaker Louis K. Keay. The subject of Mr. Keay's talk was the fabrication of T-1 steel

Wisconsin

T-1 STEEL

Hollandtown—The *Fox Valley* Section met on April 22nd for dinner and meeting at Van Abel's in Hollandtown, Wis.

Following the dinner a movie, "Positioning for Production," was shown through the courtesy of the Ransome Co.

Speaker was Louis K. Keay, manager, Technical Service, Lukens Steel Co., whose subject was "Properties, Fabrication and Uses of T-1 Steel."

WELDING OF ALUMINUM

Madison—The *Madison* Section met on Thursday, April 21st, for its last technical meeting of the season. At 12 noon, the group gathered at the Oscar Mayer Packing Co. for a cafeteria luncheon. From 1:00 to 4:00, P.M., a tour of the facilities was conducted by plant officials. Immediately following the tour, a question and answer session was held. Each visitor left the plant with a gift of the company's product.

At 6:30 the members reassembled at the Eagles Club for their regularly scheduled monthly dinner meeting. Immediately following the dinner and business meeting, a film entitled "Welding of Aluminum by the Inert Processes" was shown by Howard Adkins of Kaiser Aluminum of Chicago.

The technical meeting for the evening featured a panel discussing "Current Welding Problems." Mr. Adkins was moderator, with Mr. Nolan of Air Reduction, Mr. McKeigman of Lincoln Electric, Mr. Chevey of Linde and Mr. Griskavich of Badger Welding serving on the panel.

ANNUAL SPRING SOCIAL

Janesville—The *Madison* Section held its last meeting of the year at the VFW Club in Janesville. This was one of the highlights of the year, being the only meeting to which the ladies are invited. It was the annual spring social. Eighty-two people gathered at 6:00 P.M. on Saturday, May 7th. Each lady was presented with a pink-carnation corsage upon arrival. Following an early cocktail hour, the guests were served a delicious beef banquet, with all the "trimmings."

New officers were introduced as follows: Chairman, Elmer C. Fenske; 1st Vice Chairman, Robert Graves; 2nd Vice Chairman, James Lauridsen; Secretary, Fred Thieler; Treasurer, Gerald Duchon; Executive Members at Large—Charles Petes, Howard Rosenow, Carl Sietz, Norman Braton, Fred Gruhn, Ray Knudtson and William Branch.

A barber-shop trio from Beloit College entertained the party by playing and singing old favorites. The remainder of the evening was spent in dancing and playing cards. Following each dance, door prizes were awarded. By the end of the evening, each of the 41 ladies present received a gift ranging from an automatic pencil to a $50 electric can opener and knife sharpener.

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With this easy-to-handle torch, you can weld and braze metals that formerly required oxy-acetylene equipment. What's more, the Arcair Twin-Electrode Torch cuts costs on brazing, soldering, preheating and hard-surfacing operations. You step-up the usefulness and productivity of your electric welder. The 9000 F arc produced between the twin electrodes assures sound, strong welds — with or without filler rods. Write today for free booklet.

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Weight-saving construction • Long-life engine coupled to dual-field, self-excited, quick-response generator • Time delay for automatic idle when not welding • Single current selector, easily set for electrode size • Current peaks limited, even at extreme ends of range • Voltage self-adjusts to suit specific welding conditions • "Popouts" prevented by instant voltage recovery • Write for data.

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New Members

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MEMBERSHIP CLASSIFICATION

A—Sustaining Member
B—Member
C—Associate Member
D—Student Member

TOTAL NATIONAL MEMBERSHIP

Sustaining Members	202
Members	6,438
Associate Members	5,820
Students	280
Honorary Members	8
Life Members	16
Total	12,764

AWS Builds Men of Welding

ALBUQUERQUE

Corbin, Chester A. (C)
Penick, James W. (C)

ANTHONY WAYNE

Bruckman, George R. (B)

ARIZONA

Lopez, Ernest (B)
Meehan, Steve (B)
Schuff, R. W. (C)

ATLANTA

Dalton, William (B)
Pierce, Joe H. (B)
Seay, Edward Richmond (B)

BATON ROUGE

Walls, K. A. (B)

BIRMINGHAM

Lee, Gene H. (B)

BOSTON

Brodie, Roy N. V. (B)
Stearns, James F., Jr., (B)

BRIDGEPORT

Pickman, Edward B. (B)

CANADA

Berry, Melville D. (C)
Tracy, J. W. Frank (B)

CAROLINA

Deyton, Arleigh G. (B)
Hawk, Charles W. (B)

CHATTANOOGA

Burt, John Russell, Jr. (C)
Helmolt, Wendell Roy (C)

CHICAGO

Pauselli, Rudolph (C)
Payne, Lyle Everett (C)

CINCINNATI

Fuller, Mack L. (B)
Truman, Geo. L. (B)

CLEVELAND

Dailey, Robert W. (B)
Faulkner, John M. (B)
Jeffres, Raymond O. (B)
Ranker, John A. (B)

COLORADO

Brianza, Geo. C. (B)
Connelly, J. G. (C)
Miller, N. L. (C)
Schrameyer, Arnold F. (B)

DETROIT

Doepker, Dale E. (D)
Le Blanc, Roy (B)
Macri, Gennaro C. (B)
Milton, Bond (C)
Roskopp, Robert J. (C)

EASTERN ILLINOIS

Bennett, Floyd J. (C)
Livingston, Arthur R. (C)
Mitra, Rajat Chandra (B)
Stephens, Henry W. (B)

FOX VALLEY

Huebner, Sam A. (C)

HARTFORD

Erickson, Lennard M. (C)

HOUSTON

Aguillard, Austin (B)
Clark, B. H., Jr. (C)
Duron, Manuel E. (B)
Kachelmeier, Edward (C)
Shepherd, William L. (B)
Wilson, Robert E. (B)
Young, David E. (C)

J. A. K.

Borman, Donald F. (B)
Hanks, Ken (B)
Jones, Donald J. (B)
Unger, Howard (C)

KANSAS CITY

Meyer, W. E. (C)
Weathers, V. R. (B)

LONG BEACH

Cain, Bill M. (B)
Jenkins, Bill D. (B)

LONG ISLAND

Ebner, Wallace, F. (C)

LOS ANGELES

Mitchell, Walter G. (B)
Pridey, Gale F. (D)
Rogers, Roger W. (B)
Scott, John Robert (C)
Smith, Donald C. (C)
Wickham, Robert F. (B)

MADISON

Hoover, Roy Arthur (B)

MAHONING VALLEY

Glasnapp, William (C)
Shields, Walter A. (B)

MILWAUKEE

Andreini, J. I. (A)
Peplow, Warren G. (C)
Van Schaack, Harding (C)

NEW HAMPSHIRE

Williams, Paul A. (C)

NEW JERSEY

Reymond, Donald C. (C)
Seme, James A. (B)
Van Kirk, William T. (B)
Wilson, James G. (C)

NEW ORLEANS

Payne, Donald (B)
Ramage, A. J., Jr. (C)

NORTH TEXAS

Beauford, Clyde P. (B)
Williams, B. R. (C)

NORTHERN NEW YORK

Cothren, Jack (B)
Kittle, Donald B. (B)
Ramsay, Lawrence E. (C)

NORTHWEST

Doherty, Peter O. (B)

OKLAHOMA CITY

Leveridge, Walton S. (C)

OLEAN-BRADFORD

Paasch, Robert C. (C)

PEORIA

Cochran, David L. (D)
Crossman, Gordon C. (D)
Luster, Gary (D)
Patton, Eugene K. (D)

PHILADELPHIA

Jones, Andrew J. (B)
Oechsle, S. John, Sr. (B)
Reeser, Edward L. (D)
Scanlan, M. Ward (C)

PITTSBURGH

Beckley, Frederick H. (B)
Davis, Collin J. (C)
Hanna, William L. (C)
Hartnett, John P. (C)
Lynch, Thomas (C)
McCabe, Frank R., Jr., (C)
Strang, Russell A. (C)

PUGET SOUND

Bruce, Harold A. (C)
Crane, Clayton H. (B)
Rousseau, L. J. (B)
Waldrep, F. H. (C)

ROCHESTER

Kozlowsky, Bill (B)

SAGINAW VALLEY

Bradfield, Robert H. (C)
Hierholzer, Adolph (C)
Nagel, Lynn L. (C)
McGeoch, George D. (B)

ST. LOUIS

Jackson, Donald (C)

SAN ANTONIO

Bowman, J. E. (B)
Essary, Martin (D)
Fine, Richard (D)
Riley, James (D)
Tankersley, Dean (D)

SAN DIEGO

Merk, J. E. (C)
Miller, Jack H. (B)
Shults, James R. (B)

SAN FRANCISCO

Andrews, T. M. (D)
Blackwell, Donald A. (D)
Cutting, Cecil C. (D)
Fitzgerald, Patrick (D)
Schieve, Robert B. (D)
Stone, Lawrence (D)
Waters, Arthur D. (D)
Wilkinson, W. Neal (B)

SANGAMON VALLEY

Chaney, L. A. (B)

SANTA CLARA VALLEY

Bullis, Roy W. (B)
Graves, William J. (C)

STARK CENTRAL

Mathias, Robert W. (C)

SUSQUEHANNA VALLEY
Yanok, George P. (B)

SYRACUSE
Florence, William J., Jr. (C)

TOLEDO
Scott, Edward G. (B)

TULSA
Lee, Marvin (B)
Rudd, Vernon B. (B)

WESTERN MICHIGAN
Cressy, Charles L. (B)

YORK-CENTRAL PA.
Raber, Harry M. (B)
Tillman, John C. (C)

MEMBERS NOT IN SECTIONS
Mathis, Sherwood W. (C)

Members Reclassified During May

ARIZONA
Reilly, William P., Jr. (C to B)

CLEVELAND
Seese, Marvin W. (C to B)

HOLSTON VALLEY
Cox, George (C to B)

NIAGARA FRONTIER
Ludwig, Arthur L., Jr. (C to B)

RICHMOND
Duffey, Frank D. (C to B)

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NEWS of the industry

Welded Skyscraper

About 20 tons of welding rod was used in the erection of Western Electric Company's 31-story structure at Broadway and Fulton Sts., New York City. Designed with the assumption that the connections would be riveted or bolted, the structure was nevertheless welded at a reported saving of about $50,000. According to Wallace Heidtmann of Purdy & Henderson Associates, design consultants, there were two main reasons for the type of design selected. One is that most fabricators are not prepared for welding; the other is that, under the particular circumstances, no economy could be realized in rigid-frame design. "The irregular column spacing, location of many beams off column centers, and the many column transfer girders make it difficult to realize the full savings of continuous construction," he reported.

It is interesting to note that even under these circumstances, the Dreier Structural Steel Co., Inc., Long Island City fabricators, made the low bid based on welding.

TOPPING OUT CEREMONY

Final column is placed on the Western Electric skyscraper. Numerous "setbacks" employed in the building's profile complicated design of this structure

RWMA Reports Shipments Up

Shipments of resistance welding equipment in the first four months of 1960 increased 30% over the same period last year, according to the Resistance Welder Manufacturers Association.

New business for this period is 22% higher than that reported for the similar period last year.

Shipments during the month of April amounted to nearly $3 million, just slightly less than March.

Backlogs of almost $12 million were reported at the end of April.

Airco Markets Stainless Coils

Air Reduction Sales Co. has added a new group to its line of welding wires. Stainless-steel wire in thread-wound coils of 25 and 50 lb are now available for submerged-arc welding of Types 308, 309, 310, 347, and 502. The wires are said to conform rigidly to AWS and ASTM standards.

Nondestructive-testing Course Offered by Ohio State

The Department of Welding Engineering of The Ohio State University offers an intensive two-week course in nondestructive testing from Sept. 12 through 23, 1960. The course will be held 8 hours a day, five days a week and will cover (1) the basic principles of all forms of nondestructive testing and their industrial application, (2) advantages and limitations, (3) equipment, procedures and techniques and (4) interpretation. A complete line of laboratory equipment is to be used.

Instruction will be given by Robert C. McMaster, editor of the *Nondestructive Testing Handbook* which is used as text; Professor R. B. McCauley, chairman of the Department of Welding Engineering; William L. Green and others. The fee is $200. Further details may be obtained from Department of Welding Engineering, 190 W. 19th Ave., The Ohio State University, Columbus 10, Ohio.

INCO Appoints Officers

L. E. Grubb has been elected vice-president—sales and E. M. Kline vice president—operations of the Huntington Alloy Products Division of The International Nickel Co., Inc., Henry S. Wingate, Chairman of the Board of the company, announced recently. The election of John A. Marsh, as President of the Division, was also announced.

At the same time, G. K. Crosby was made assistant vice president—administration, J. M. Weldon, assistant vice president—sales and

COMING EVENTS

A Calendar of Welding Activity

AWS

1960 National Fall Meeting. September 26–29. Penn-Sheraton Hotel, Pittsburgh, Pa.

1961 Annual Meeting & Exposition: April 17–21. Hotel Commodore, New York, N. Y.

Oct. 13–15. Western Welding Show, Exposition Hall, Santa Clara County Fair Ground, San Jose, Calif.

ASM

Oct. 17–21. 42nd Annual Metal Show. Trade and Convention Center, Philadelphia, Pa.

J. E. Carter, assistant vice president—manufacturing of the Huntington Alloy Products Division, according to Mr. Wingate.

New NCG Package

A moisture-resistant carton to protect their "Sureweld" electrodes has been introduced by National Cylinder Gas Division of Chemetron Corp. The NCG package is said to open easily by means of a tear tape and a color code will identify the type rod contained.

Syntron Adds Plant, Appoints Distributor

An additional 80 employees will be required to staff the 16,000-sq ft air-conditioned plant scheduled for completion in August for the Syntron Co., Homer City, Pa. Employing their exclusive double-

diffusion process, the company expects an eight-fold production increase to result from the expansion.

Also announced was the appointment of Robert O. Whitesell and Associates as sales and engineering representatives for the central states area. This company maintains offices in Indianapolis, Cleveland, Cincinnati and Dayton.

United States Welding Moves

The opening of the new 15,500-sq-ft plant of the United States Welding Works Co., Inc., 600 S. Santa Fe, Denver 23, Colo., was celebrated with a two-day welding show. About 2000 people attended the demonstrations and exhibits on March 25–26.

The latest move is the third in the growth of the company according to R. Lofgren, Jr., president. Other branches are located in Scottsbluff, Neb.,; Sterling, Colo.; Cheyenne, Wyo.

C&C Welding Holds Show

A two-day Weld-O-Rama and open house was held on May 25–26 in Salt Lake City jointly by C&C Welding Supply Co. and Linde Co., Division of Union Carbide Corp. The new facility, located at 999 S. Redwood Rd., includes the oxygen and acetylene production units of Linde Co. and the Salt Lake City store of C&C Welding Supply.

The latest methods for the joining and severing of metals was demonstrated by factory representatives from Linde Co., Fibre Metal Products Co., Kedman Co., All State Welding Alloys Co., Miller Electric Co. and Heath Engineering Co.

Budd Acquires Metrol Inc.

The Budd Co. has acquired the assets of Metrol Inc., manufacturers of electromagnetic nondestructive testing equipment with headquarters in Pasadena, Calif. The announcement was made by John H. Buck, vice-president.

Metrol will continue to operate in California for the present as a new department of the Instruments Division according to Dr. Buck. He added that Richard Hochschild, Metrol's president, is joining The Budd Co. on a full time basis. Donald Erdman will act as consultant on eddy-current testing.

Among Metrol products are: Radac, a multiple frequency electromagnetic inspection instrument for metals; Heatcheck, an all-transistorized instrument for identifying alloy and properties in metals; and an all-transistorized, portable electromagnetic thickness gage for measuring sheet foil and plating in nonferrous and ferrous metals.

RWMA Members Visit Ohio State University

On April 8th, members of the Resistance Welder Manufacturers' Assn., visited the campus of Ohio State University to see the facilities of the Department of Welding Engineering and to learn of current educational efforts in resistance welding. Professor Roy B. McCauley, chairman of the Department of Welding Engineering, gave an informal talk.

Dr. H. G. Taylor, director of the Electrical Research Laboratory in England and head of Commission III of the International Institute of Welding, who is visiting in this country, spoke at luncheon on developments in resistance welding in England.

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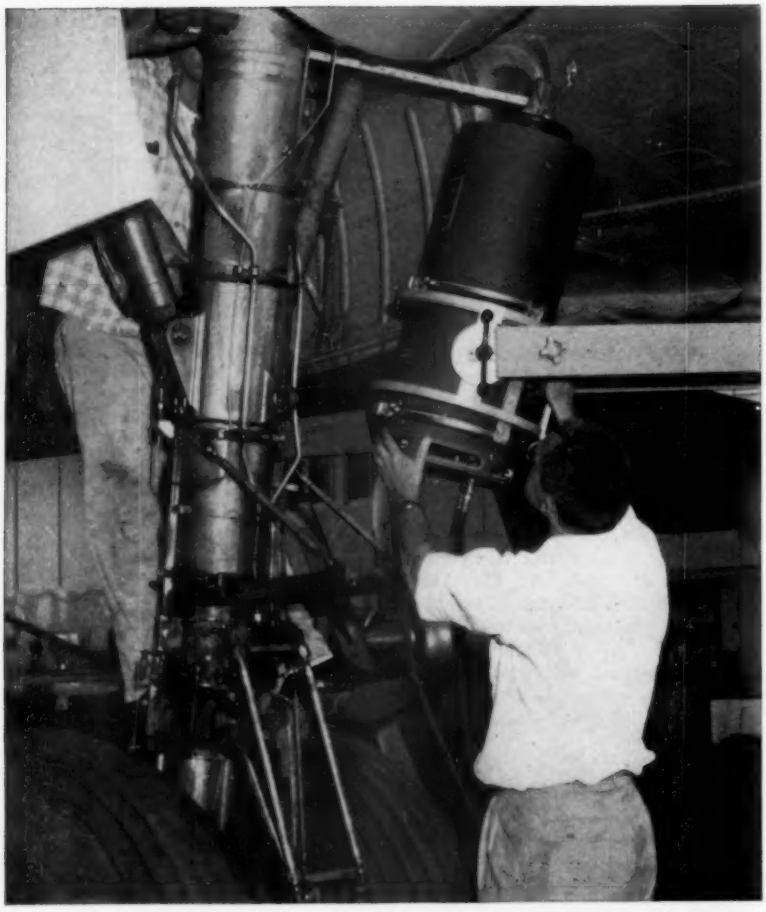

Here the light-weight transformer head of a 300 KV Model is being positioned to X-ray a circumferential weld in an airliner landing gear strut.

High KV X-ray with 100% Duty Cycle

Triplett & Barton 100% duty cycle X-ray may double the number of exposures a day — save vital time and dollars.

The fully loaded, ready to operate Triplett & Barton head on the 275 KV Model weighs only 65 lbs. That light weight means easier portability, quicker setups — more time and dollars saved.

And Triplett & Barton's high KV (up to 300 KV *with a full 10 milleamperes output*) allows for shorter exposures with the required definition — more time and dollars saved.

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INDUSTRIAL X-RAY
MAGNETIC PARTICLE

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The program was arranged by T. Embury Jones, president of precision Welder and Flexopress Corp. in Cincinnati, Ohio, and H. V. Beronius, Jr., sales and engineering manager for Swift Ohio Corp. in Kenton, Ohio.

Victor Buys L&B Welding

Victor Equipment Co., San Francisco, has acquired L&B Welding, Inc., Berkeley Calif., manufacturer of machines for the rebuilding of tractor track rollers, idlers and rails, announces L. W. Stettner, Victor president. The acquisition will be operated as a wholly owned subsidiary, with manufacture to continue at the present plant in Berkeley. L&B executives Turner G. Brashear, Forest Leader and Clifford Leader will remain in management capacities.

Present plans call for marketing the L&B product line under the Victor name through Victor dealers throughout the United States, Canada and the export field.

United Welders Names Marshall Machinery

The George A. Marshall Machinery Co., Charlotte, N. C., has been appointed to represent United Welders, Inc., in the states of Virginia, North and South Carolina. United Welders, Inc., Bay City, Mich., builders of automatic welding and processing equipment, will also be represented by Marshall's branch office in Richmond, Va.

WELDING IN GOOD FORM

Actress Juli Reding, crowned "Miss Welder of 1960," gets a couple of pointers on welding from Clifford S. Tallman of Eutectic Welding Alloys Corp., annual sponsors of the event

Eutectic Opens New Center

A training and service center for the area including Minnesota, North and South Dakota and Northern Wisconsin was opened May 2nd by Eutectic Welding Alloys Corp. The Great Lakes Division will offer free training in welding and will serve as a warehouse center for the region.

Airco Wins Safety Awards

Thirty-four plants of Air Reduction Co., Inc., have been awarded certificates of safety achievement for 1959 by the Manufacturing Chemists' Assn., Inc., Washington, D. C. The awards, given annually to plants that complete a calendar year without a lost-time accident, have been made to 475 plants throughout the country.

United Specialties Appoints Industrial Equipment Co.

United Specialties, Inc., El Dorado, Ark., announces the appointment of Industrial Equipment Co., 1144 W. Baltimore Ave., Detroit 2, Mich., as exclusive manufacturer's sales representative for their industrial hose and cable reels in Michigan.

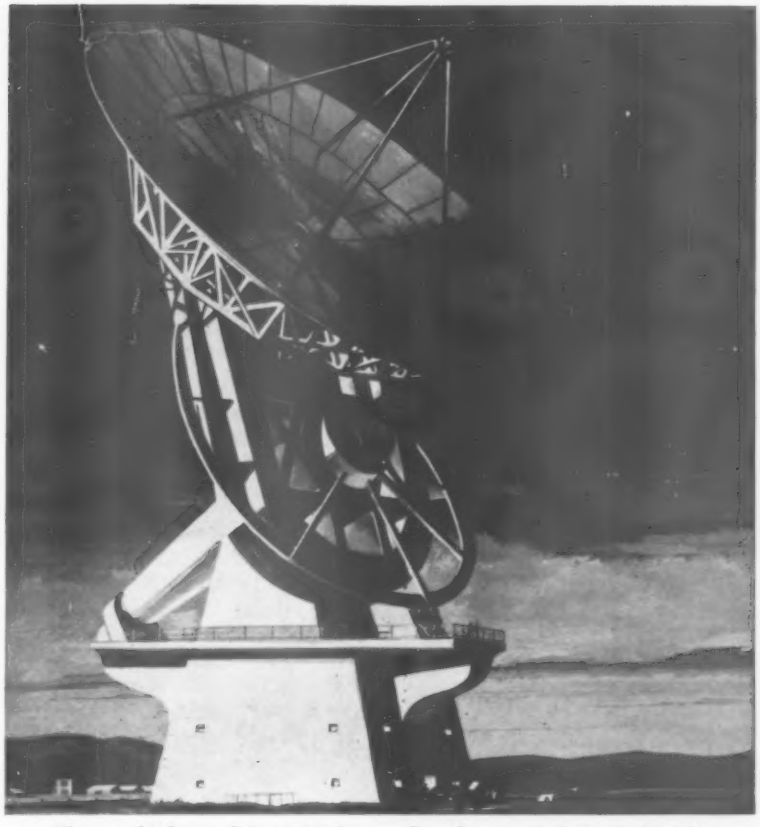
New Canadian Gas Plant

A new plant producing oxygen, nitrogen and acetylene has been placed on stream in Edmonton, Alberta, by the Alberta Oxygen & Acetylene Co., Ltd., a subsidiary of Chemetron Corp., Chicago. The new facilities, located in the East Edmonton industrial district, triple the company's producing capacity in the area. Operations have been discontinued at the former plant, on 142nd street.

It is reported that the increased production of industrial gases will help fill the needs of the steel, fabricating, metalworking, oil, natural gas, chemical, welding, construction and other industries in the province of Alberta and in portions of Saskatchewan and British Columbia.

Distributor for "Warco" Presses

Neff, Kohlbusch & Bissell, Inc., Chicago, Ill., announced that their firm has been appointed sales and service representatives for The Federal Machine and Welder Co.'s line of "WARCO" mechanical presses. The newly appointed representatives cover the Chicago and north central Illinois area, northwest Indiana and Iowa.



The one-third acre disk of this huge radio telescope, built by E. W. Bliss Co., turns on a 22 foot support bearing. Sperry ultrasonic testing was used to search the bearings' eight 4 inch plates for laminations and to thoroughly probe the vital welds.

Sperry Ultrasonics Tested the Key Welds

Whether it's this giant radio telescope, a gas transmission line or a vital pressure vessel, the nondestructive testing of key weldments has become standard procedure.

This is a major reason for Sperry's planned expansion in nondestructive test equipment. Both the new Sperry services are of the highest quality. Triplett & Barton X-ray offers light weight (the transformer head of the 300 KV model weighs less than 70 lbs.), continuous duty cycle, and high power (up to 300 KV with a full 10 milleamperes output). Sperry SONOFLUX® magnetic particle systems offer the exclusive features of infinite current control and fast, two second demagnetization.

Sperry is fully equipped to evaluate your weld inspection problem and advise the best solution.

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In multiple gun welding presses several load cells can be set in position and force read with only a single dial indicator.

Design of load cell (only ⅝" between load points) is ideal for checking electrode force, as well as setup and maintenance of other mechanical or hydraulic equipment.

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Superior Electronics Enlarges

Superior Electronics Co., Minneapolis welding sales and service firm, and manufacturer of the "Weld Rite" line, announced that it has moved its operations into new and larger quarters. Superior's new plant is located at 1011 S. 5th St. near the Minneapolis loop, and provides the company with more than 4500 sq ft of manufacturing, sales and office space.

Mullenbach Appoints Ransome

Mullenbach Division of Electric Machinery Manufacturing Co., Los Angeles, announces the appointment of Ransome Co., Scotch Plains, N. J., as National Sales Agents for Mullenbach's Arctrol, a portable remote foot control for welding machines. Mullenbach will continue to service selected established accounts.

Murchie and Roberts Named

The Stulz-Sickles Co. of Elizabeth, N. J., has recently announced the appointment of Donald J. Murchie (AWS), as sales manager.

It was also announced that Phillip J. Roberts has joined the company as district sales manager for metropolitan New York, New Jersey and Philadelphia. Mr. Roberts was formerly with RCA.

Shieldalloy Opens Office

A new sales office has been established in Pittsburgh by Shieldalloy Corp., Newfield, N. J., producers of ferro alloys, master alloys and metals, processed minerals and ores. The office, located in the Oliver Building, will serve specialty steel producers, foundries and other users of metallurgical materials in Western Pennsylvania and Ohio.

LIQUID OXYGEN STATION

The addition of a 2760-gal liquid oxygen tank at Goss Brothers Welding Supply, Falls Creek, Pa., enables this Airco distributor to fill cylinders or supply liquid bulk

Balteau Names Distributor

The appointment of Watland, Inc., Chicago, Ill., as midwestern distributors of its line of portable industrial X-ray equipment was announced recently by Maurice Marechal, vice president and general manager of the Balteau

Authors...

please note!

All authors interested in presenting papers at the AWS 42nd Annual Meeting to be held in New York City on April 17–21, 1961 are advised of a change in preliminary arrangements.

The usual forms, "An Invitation to Authors" and "Author's Application Form," were printed as a detachable insert in the May issue of the Welding Journal instead of being sent through the mails.

Additional copies of the forms may be obtained by writing to AWS Headquarters, 33 West 39th St., New York 18, New York.

Electric Corp. The Watland organization, the largest distributor of photographic equipment and supplies in the midwest, travels 10 field representatives and will cover the Illinois, Michigan, Wisconsin and Indiana territory for Balteau.

Ransome Names Distributors

The Ransome Co., Scotch Plains, N. J., has announced the appointment of two new distributors. J. A. Cunningham, 2025 Trenton Ave., Philadelphia, Pa., has been appointed distributor for Eastern Pennsylvania and Southern New Jersey; and Brooks Welding Supply Co., Chattanooga, Tenn., has been appointed distributor for Central Tennessee.

In addition, it was announced that the company's standard line of positioners, turning rolls, welding-head manipulators and other Ransome welding products will be manufactured in France by the Petro-Fouga Co. of Paris.

To Lease Cable Reels

Automatically retractable hose and cable reels may now be obtained by lease according to a recent announcement from United Specialities, Inc., El Dorado, Ark. The Weld-Reel and Reel-King may be leased from one to five years.

Arcwire Extends Plant

Arcwire Corp. is enlarging its Mt. Carmel, Pa., plant to supply the growing needs of the stainless steel and aluminum products industries for welding wire. Arcwire, a subsidiary of the Arcos Corp., Philadelphia, draws welding quality stainless steel and aluminum wire.

The announcement was made by R. David Thomas, Jr., president of Arcwire. In describing the building, Mr. Thomas said that it is a prefabricated structure with a framework of welded steel columns and trusses which will span the 60-ft width of the building without inside columns. The choice of this type of construction will permit continued expansion through unbolting the end wall and inserting additional bays.

Welded frame of new Arcwire plant

M&T Declares Dividends

Directors of Metal & Thermit Corp., declared a dividend of 30 cents per share on the common stock, it was announced by H. E. Martin, president. The dividend is payable March 17, 1960, to shareholders of record at the close of business on March 7, 1960.

The directors also declared the regular quarterly dividend of 87½ cents per share on the preferred stock, payable March 28, 1960, to stockholders of record at the close of business on March 18, 1960.

Lecture Arouses Interest

While scheduling an in-plant training program to update welding personnel on the subject of gas tungsten-arc welding of pipe, Kaighin & Hughes, Inc., Toledo, Ohio, extended an invitation to local industries.

The unexpected response resulted in over 150 reservations. R. H. Hoefler, chief welding engineer of K&H, noted in giving the lecture demonstration, a high degree of interest. K&H do not sell welding equipment but were simply sharing data with local industrial personnel. The high interest shown once again reveals the desire for welding education at engineering and management levels.

Nottingham Makes Appointments

Gulf Coast and Cleveland area sales representatives for its welding and portable lighting and power distribution equipment and systems have been appointed by J. B. Nottingham & Co., Inc., 441 Lexington Ave., New York 17, N. Y.

Charles Petty, Jr., 4025 Sierra Dr., Mobile, Ala., will represent the company in the Gulf Coast area, from Mobile through Houston, Tex. He has been an executive of The Ingalls Shipbuilding Corp. in Pascagoula, Miss.

Floyd Davies, 14712 Leonard Ave., Cleveland 7, Ohio, will represent the company in that city and surrounding industrial area. A former executive of Erico Products, Inc., he has had extensive experience in electrical and welding fields.

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PERSONNEL

Sander Advances to New Post

C. P. Sander was recently appointed general superintendent, Los Angles District, of U. S. Steel's Consolidated Western Division. Mr. Sander was previously general Superintendent of the Vernon plant. At the same time, appointments were announced for John J. McNerney who advanced from general superintendent — Maywood plant to assistant to the vice-president—production and for Harold C. Seiler who moved from plant superintendent—Maywood plant to assistant general superintendent—Los Angeles District.

Mr. Sander will be responsible for production and staff activities for the Los Angeles District. His long record of experience in this field includes service in various engineering capacities prior to joining the Western Pipe and Steel Co. in 1934. When this company was acquired by U. S. Steel Corp., in 1948, he continued as general superintendent of the Vernon plant.

A past president of AWS, Mr. Sander has been active in many phases of SOCIETY work including the Board of Directors, the Western District and most recently the general chairmanship of the Arrangements Committee for the 41st Annual Meeting and Exposition at Los Angeles.

In addition to membership in civic and social groups, he is a member of the American Society for Metals, American Petroleum Institute and Pacific Railway Club.

C. P. Sander

Oyler to Head Research

Glenn W. Oyler AWS was recently named head of the Welding Research and Development department at M&C Nuclear Inc., a subsidiary of Texas Instruments Inc., Attleboro, Mass. He will be responsible for the conception and development of new methods and techniques for assembling nuclear fuel elements and allied components by welding.

Dr. Oyler received a B.S. degree from Pennsylvania State University, M.S. degree from the University of Pittsburgh and Ph.D. from Lehigh University, all in metallurgical engineering. At Lehigh he won the first Linde Co. Graduate Fellowship. Prior to joining Texas Instruments, he worked for the Linde Co., Newark, N. J., as head of the Sales Development Division of Electric Welding.

He is the author of several papers on the pressure welding of aluminum, the inert-gas welding of metals, the plasma arcs and other subjects. He holds several patents in the gas-shielding and plasma-arc fields.

Glenn W. Oyler

Murphy Heads Distributor Area

Joseph J. Murphy AWS has been named district representative of the Middle Atlantic States for Hobart Brothers Co., Troy, Ohio. Mr. Murphy will supervise the distribution of Hobart arc-welding equipment, electrodes and accessories

Joseph J. Murphy

Otis H. Young

William B. Payne

Fred L. Siegrist

in Pennsylvania, New Jersey, Delaware, Maryland, Washington, D. C., and Va. He was associated with Hobart Welders Sales Co., Philadelphia, for eight years.

Young Made Regional Manager

Otis H. Young AWS was appointed manager of the west central region for the Welding Products Division, Metal & Thermit Corp., with regional headquarters at East Chicago.

Mr. Young, a mechanical engineer from the University of Illinois, joined M&T in 1951 as a welding salesman in the Chicago district.

Payne Is Sales Manager

Progressive Welder and Machine Co. has announced the appointment of William B. Payne AWS as general sales manager. Mr. Payne has been with Progressive since 1948, in the service, planning and sales departments. He studied electrical engineering at Michigan State and Wayne State universities.

In his new post, he will head the marketing of regular resistance-welding equipment as well as special welding and assembly fixtures from the Special Machinery Division in Pontiac, Mich.

Siegrist Assistant Editor

Fred L. Siegrist AWS was appointed assistant editor of *Metal Progress*, publication of American Society for Metals. Mr. Siegrist brings to his new position a varied background of technical experience. He was training supervisor for ASM's home-study school for the past three years. Prior to that he served as metallurgist at the Lafayette, Ind., plant of Alcoa, at the Woodridge, N. J., plant of Wright Aeronautical Corp. and at the Westinghouse Electric Corp., Pittsburgh.

Mr. Siegrist is a metallurgical engineer from the University of Illinois and a member of several honorary and engineering societies.

Mitchell Made Sales Engineer

Edward P. Mitchell AWS has been added as a sales engineer to the Eastern Region sales staff of the Welding Products Division, A. O. Smith Corp., Milwaukee, Wis.

In his new position, Mr. Mitchell is responsible for welding electrode and machine sales in New York City and neighboring New Jersey counties. He reports to James B. Ray, Welding Products Northeast District sales manager.

Bajari, Henderson Promoted

William Bajari AWS of Norwalk, Calif., has been made field representative for the Arcair Co., Bremerton, Wash. He will work with the company's distributors and call on industries in 13 western states. For many years he has been associated with the welding industry in its various phases.

Richard Henderson AWS has been appointed chief engineer for the Arcair Co., Lancaster, Ohio. In this capacity he will be in charge of all product design, research and development for Arcair. A registered engineer, he has worked in various engineering capacities before coming to Arcair.

DeSanto Joins Sales

Joseph DeSanto has joined Air Reduction's sales staff at Chicago, Ill., it was announced by G. J. Dekker, district manager. Mr. DeSanto, with his more than 15 years of arc welding sales experience in heavy industrial applications, will be responsible for sales-engineering duties connected with Air Reduction Sales Co.'s electrode business in the Chicago area.

Professor Henry Retires

After 41 years of teaching at the Polytechnic Institute of Brooklyn, Otto H. Henry retired last April 28th. Professor Henry is regarded as a leading engineering educator, industrial consultant and pioneer in the field of metallurgy. The occasion called forth more than 200 tributes from former students, associates and friends who testified to the great stimulation they received from his teaching and leadership.

Dieker Named Assistant

Kenneth G. Dieker has been appointed assistant to the midwestern regional manager for National Cylinder Gas Division of Chemetron Corp., 840 N. Michigan Ave., Chicago, according to C. D. McGuinn, NCG vice president.

Mr. Dieker formerly was general sales manager for the Venezuelan division of NCG International in Caracas.

Sorensen, Caine, Romo Advance

Eutectic Welding Alloys Corp., Flushing, N. Y., has made three new appointments according to Rene D. Wasserman, president.

William F. Sorensen was made national distribution manager in charge of all service and training centers.

Harold P. Caine was named regional manager for the southern region with headquarters in Atlanta, Ga.

Robert C. Romo was named manager of a new service and train-

Edward P. Mitchell

William Bajari

Richard Henderson

EMPLOYMENT OPPORTUNITY FOR ENGINEER

AWS is seeking an engineer to join Headquarters' Technical Staff as Assistant to the Technical Secretary.

Here are the duties—

Working with AWS technical committees in gathering and correlating technical data; preparing minutes, reports and other records of committee activities; editing standards for publication as completed.

Disseminating technical information in answer to inquiries from industry.

Related duties as assigned.

Here are the qualifications—

Ability to work with technical men at all levels in a cooperative manner. This is necessary to deal successfully with committee personnel, AWS members and the general public.

A degree in engineering, any branch.

At least three years' experience in engineering work, preferably in welding or allied fields.

Here is an opportunity—

The man we are seeking has initiative and imagination and is interested in becoming familiar with welding in all its aspects and for every type of application. Salary will be commensurate with qualifications and experience.

If interested in being interviewed for this position, send a resume* of your education, experience and personal background to

Technical Secretary

American Welding Society

33 West 39th Street

New York 18, N. Y.

* Will be held confidential.

ing center set up in Minneapolis. He is in charge of distribution in Minnesota, North and South Dakota and Northwestern Wisconsin.

McNeill Made Representative

S. W. McNeill has been appointed factory representative for the National Welding Equipment Co. of San Francisco. Mr. McNeill was formerly employed in a similar capacity and will represent National in Southern California, Nevada, Arizona and New Mexico.

Korssell Made Salesman

Herbert F. Korssell has been appointed a sales representative for the Plastic Metals Division of National-U. S. Radiator Corp., Johnstown, Pa., it was announced by Charles E. Hanson, sales manager. Plastic Metals, the oldest producer of iron powder in the United States, is also the nations largest producer of high purity electrolytic iron.

Mr. Korssell will promote the sale of Plastic Metals products in western Indiana, Illinois, Wisconsin, Minnesota and Missouri. He will maintain headquarters at the company's branch office at 625 N. Kedzie Ave., Chicago, Ill.

Before joining Plastic Metals, Mr. Korssell was employed by Fansteel Metallurgical Corp., for two years, after which he held the position of assistant plant manager for Powdered Metal Products Corp. of Franklin Park, Ill., for thirteen years.

Leinenkugel Foreign Product Sales Head

James M. Leinenkugel has been appointed product manager—distributive products for A. O. Smith International S.A., according to an announcement recently by J. J. Gibbons, director of marketing for Smith's international operation.

Leinenkugel replaces Fred Bote who has resigned to accept a position with another company. Leinenkugel has spent the last four years in Maracaibo, Venezuela, as manager of a machinery distributor. Prior to that, he was with A. O. Smith in a number of capacities, including engineering trainee in the Vessel Division, sales engineer in the International Division and as sales supervisor of deep well turbine pumps. He is an engineering graduate of the University of Wisconsin.

Binkerd Assumes New Post

R. H. Binkerd was appointed general sales manager of NRC Equipment Corp., Newton, Mass., a leading producer of high vacuum equipment and accessories, and a manufacturing subsidiary of National Research Corp. Mr. Binkerd will have full responsibility for formulating over-all sales policies and for supervising the activities of the company's field staff and distributors.

Previously he had been with Alco, a manufacturer of diesel locomotives, nuclear equipment, pressure vessels and other lines of industrial products since 1942, and formerly was associated with a large New York advertising agency.

McKeighan Cited by Lincoln

J. S. McKeighan, Milwaukee district manager for the Lincoln Electric Co. has been named "Man-of-the-Year" of the Lincoln sales-engineering organization. William Irrgang, company president, cited McKeighan's leadership and management under which sales of Lincoln arc welders, welding electrodes and accessories, electric motors and battery chargers increased to 146 per cent of the 1958 period.

Henry Elected Director, Fechtmeyer Is Vice-president

J. P. Henry, Ampco Metal, Inc., vice-president and general sales manager has been elected a director and Henry C. Fechtmeyer has been named a vice-president of the Milwaukee bronze alloy producing firm.

Mr. Henry joined Ampco in 1940, serving in sales and engineering capacities. He has headed the general sales division since 1955.

In addition to his new position, Mr. Fechtmeyer will continue as the firm's secretary and controller. He has been associated with Ampco since 1943 and was appointed a director in 1952.

Hudson Appointed Sales Manager

James A. Hudson, formerly Midwestern Manager of Gas Products Sales, has been appointed Western Sales Manager of Bulk Gas Sales by Linde Co., Division of Union Carbide Corp. He will be engaged in the sales and promotion of on-site tonnage oxygen plants to the steel, chemical and petroleum industries. Hudson joined Union Carbide Corp. in 1934 during the construction of their Whiting, Ind., chemical plant.

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.....BE ACTIVE!

Offord Made Sales Engineer

Appointment of Donald T. Offord as sales engineer in the Chicago area has been announced by Elmer J. Lell, vice president, Colmonoy Division, Wall Colmonoy Corp.

Mr. Offord has been engaged in welding engineering work for the past 17 years, having worked with Ethyl Research Corp., Chrysler Jet Engine Division and Edwards Trailers. Prior to joining Wall Colmonoy, he was with Continental Aviation and Engineering as a welding supervisor.

Engstrom, Poethig Promoted

Ralph H. Engstrom and Robert E. Poethig were elected vice presidents of the Bastian-Blessing Co., Chicago, at a board meeting on April 1, 1960.

Mr. Engstrom joined the company in 1937 and has held a series of positions in the company's sales department, most recently serving as assistant vice president. He will continue as general sales manager of the RegO Division.

Mr. Poethig joined the RegO sales department as assistant sales manager in 1939 and became director of engineering and research, the title he retains as vice president.

Martin Field Representative

Herbert L. Martin has been appointed field representative for the Arcair Co. in the central United States. His duties will include working with distributors and industries in that area.

Mr. Martin for many years has been closely associated with metalworking and industrial welding processes.

Van Dame Elected Director

R. J. Van Dame was elected to the board of directors of The Lincoln Electric Co., Cleveland, Ohio, at the company's annual shareholders meeting. Mr. Van Dame has been controller since 1947. He started in the accounting department in 1928 following his graduation from Fenn College.

Stevens Heads District

J. S. Stevens has been appointed district manager of Air Reduction Sales Co.'s Birmingham office, it was announced by H. C. Wallace, regional sales manager of Airco's southern region. As district manager, Mr. Stevens is responsible for the sale and distribution of all Airco products marketed through the Birmingham facilities located at 124 S. 16th St. Birmingham 3, Ala. Mr. Stevens succeeds J. M. Crockett, who has been transferred to Airco's head office in New York.

Mr. Stevens joined Air Reduction in 1936 shortly after attending the University of Illinois. He has served the company principally as a specialist in the railroad department. His most recent position was assistant manager of sales at Airco's Charlotte, N. C., office. Mr. Stevens will continue to serve as southeastern railroad zone manager.

Welding Supply House Dedicated

Northern California's newest and most modern welding service center was dedicated November 20th at Littrell Welding Supply, 653 N. Market St., in Redding.

Vice-Mayor Wilbur Simmons of Redding and other civic dignitaries assisted Kenneth Kline, manager, and E. R. Batson, president, of Littrell, in a special dedication ceremony preceding an open house at the facility. The new installation represents an investment in excess of $45,000.

WELDING ENGINEER

The Allis-Chalmers Manufacturing Company, Hydraulic Division, at York, Pennsylvania, has an opening in its Manufacturing organization for an experienced Welding Engineer. Engineering degree desirable.

Applicants should have experience in heavy fabrication with a knowledge of metallurgy, being capable of developing techniques for the fabrication of alloy materials.

Salary commensurate with experience and ability to work with a high degree of independence.

Send resume to:

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Abstracts of Current PATENTS

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Commissioner of Patents, Washington, D. C.

2,912,550—Welding Method and Apparatus—Herbert Harris, Johnstone, Scotland, assignor to the Babcock & Wilcox Co., New York, N. Y.

In Harris' method, steel tubular members are united by raising the temperature of the metal at the ends of the members by induction heating to welding temperature and maintaining this temperature constant until the union of the members has been effected. The members are pressed together with a pressure at least 0.15 ton psi but not exceeding 1 ton psi.

2,912,562—Method and Apparatus for Reconditioning Cylinder Liners for Diesel Engines—George C. Donovan, Lincoln, Neb.

In this reconditioning method, the liner being processed has an outer water jacket provided thereon and a cooling fluid is circulated through this outer jacket on the liner while the liner is rotated about its longitudinal axis. A layer of weld metal is simultaneously deposited on the inner surface of the liner while it is being rotated.

2,912,612—Electrode Wire-Feeding System—Edward J. Brady and Claire Bond Marshall, York, Pa., assignors to Alloy Rods Co., York, Pa., a corporation of Pennsylvania.

This patent is on an electrode wire-feeding system wherein an electrode wire is removed from a stationary reel by uncoiling the wire spirally from one end of the reel. Feed roll members are present to engage the electrode wire to push it through a tubular conduit for weld action. Straightening means are associated with the apparatus to straighten the electrode wire within two planes substantially transverse to each other to insure feeding of the electrode wire accurately to the arc at the end of the tubular-feed conduit to avoid oscillation of the wire at the weld nozzle.

2,913,567—Welding Machine and Method—Desmond Stolz, Milwaukee, Wis.

Stolz' patent is on a welding machine for forming a grating structure having a plurality of longitudinally extending primary bars spaced apart by interconnecting secondary bars that abut primary bars at welded contact portions provided therebetween. The machine includes, among other members, a plurality of longitudinally spaced pairs of welding electrodes mounted on the machine frame, and means for keeping the primary and secondary bars in alignment with the electrodes for welding action.

2,913,618 — Welding System — George G. Glenn, Oakland, and William W. Gibson, Alameda, Calif., assignors to Glenn Pacific Powers Supply Corp., a corporation of California.

In this patent, a wire feed system for welding equipment including an alternating current drive motor is provided. Other means are present and are operatively connected to the motor to reverse the lead means connecting thereto while the motor is running so as to effect a prompt braking of the motor. The patent particularly covers the specific features of the motor reversing means and action thereof.

2,914,641 — Welding Dissimilar Metal Members—Eugene V. Yuhasz, Fanwood, N. J., assignor to Union Carbide Corp., a corporation of New York.

The present patent is on a process for welding together a first metallic member having a first melting temperature and having a hollow section of given contour and a second but dissimilar metallic member having a second melting temperature higher than the first melting temperature and with a projection of contour and size corresponding to the hollow section. The projection on the second metallic member is coated with an intermediate bonding material having a melting temperature intermediate those of the first and second members. A high-frequency magnetic field is established adjacent the first metallic member to expand it and the coated projection on the second member is inserted into the expanded hollow section and the induction heating action is continued until the intermediate bonding material forms an alloy between the first and second metal members.

2,914,651—Automatic-Welding Fixture for Crusher Rollers—Robert M. Ackerman, Minneapolis, Minn.

This new welding fixture is for use in resurfacing worn cylindrical rolls. In the fixture, means are provided for depositing a bead of weld metal onto the roller as the roller is rotated and other means are present to shift the depositing means axially relative to the roller, while switch means and other controls responsive to the rotation of the roll are present to actuate the shifting means only once for each revolution of the roller whereby a succession of adjacent annular beads are provided on the roller.

2,914,652—Welding-Machine Electrodes—Preston M. Hall, Silver Spring, Md., and Richard H. Taylor, Bridgeport, Conn.

The electrode holder disclosed is for use in electrical resistance welding machines. In general, the holder includes an outer tube for clamping upon a welding machine, and an inner tube slidable in the outer tube passageway and projecting from an end of the outer tube and being adapted to support an electrode. An electric current conducting sleeve is connected at opposite ends to the inner tube and outer tube and is itself longitudinally extensible and contractable to aid in securing the inner and outer tubes together.

2,914,654—Method for Joining Electrodes—Carl Lundahl and Sven Lundahl, Malmo, Sweden, assignors to Allmanna Svenska Elektriska Aktiebolaget, a Swedish corporation.

This patent on joining electrodes is for use in submerged-arc welding and in it the electrodes, which are straight, are fed downwardly in a longitudinal direction and the tongue on one end of each electrode is caused to enter a corresponding slot formed between parallel tongues on the opposite end of the preceding electrode. These parallel tongues are pressed closely upon the tongue of the other electrode so that the leading end of each electrode would be secured to the trailing end of the preceding electrode.

2,914,848—Method of Brazing Titanium—Bernard S. Blum, New York, N. Y., and Edward J. Philipps, Fair Lawn, N. J., assignors to Curtiss-Wright Corp., a corporation of Delaware.

A titanium part is to be joined to another part by the method of this invention and the parts are placed in abutting relation in the presence of a brazing alloy. This alloy consists of 1 to 20 parts tin, 1 to 6 parts aluminum with the balance substantially all silver. The parts are then brazed together at a temperature of approximately 1600° F.

2,915,617—Stud-welding Gun—Samuel O. Jones, Newport News, Va., assignor to Newport News Shipbuilding and Dry Dock Co., Newport News, Va., a corporation of Virginia.

Jones' patent is on a welding gun wherein a pair of telescopically engaged cup elements are received in a bore in the frame. A plunger slidably extends through the end wall of one cup member and has current carrying means fastened to the other end exteriorly of the first cup and controlled thereby to determine the outermost position of the second cup. Other special means complete the gun.

2,916,600—Gas-shielded Metal-arc Welding—Peter W. Tichler, Nijmegen, Netherlands, assignor to Union Carbide Corp., a corporation of New York.

This process is for using a fusible electrode to weld parts to be joined together where the parts are positioned in a substantially vertical plane and the joint to be welded is situated substantially horizontally. One of the parts to be joined has a rectangularly cut abutting edge and the other one has a bevel on at least one side. In the method, the rectangularly cut part is positioned on top of the beveled part and the electrode is pointed slightly upward. The welding is accomplished in a protecting gas atmosphere.

2,916,601—Electric-arc Welding—Alexander Lesnewich, New Providence, N. J., assignor to Air Reduction Co., Inc., New York, N. Y., a corporation of New York.

A method of imparting conical rotation to the molten metal supplied from a consumable metal electrode by a high current density self-regulating arc established in a substantially inert atmosphere is disclosed in the present patent. The electrode is so fed into the arc as to be deformable by the reaction forces of the arc and the release of molten metal and metal vapor from the arcing terminal whereby rotation is imparted to the arc and the molten metal therein. The desired location is effected by controlling the relationship between the electrode diameter in relation to the magnitude of the arcing current supplied to the electrode.

2,916,603—Welding Method and Apparatus—Stanley C. Shappell, West Boxford, Mass., assignor, by mesne assignments, to Sylvania Electric Products Inc., Wilmington, Del., a corporation of Delaware.

A method of welding a lead-in wire that projects substantially axially from an electrical device and extends through a pin of a base of the device is taught in the present patent. In the method, relative movement is produced between a welding electrode and a portion of the lead-in wire that extends outside and beyond the base to bring them into engagement with one another at a point intermediate the ends of the lead-in wire to effect severance of a part of that portion of the lead-in wire that extends outside and beyond the base pin. The remainder of the portion of the lead-in wire is welded to the base pin.

2,916,605—Three O'Clock Welding Apparatus—John W. Lucas, San Marino, Calif., assignor, by mesne assignments, to Yuba Consolidated Industries, Inc., San Francisco, Calif.

Lucas' apparatus is for use in joining vertical plates along a horizontal seam by submerged-arc welding. The apparatus provides an endless flexible element having a portion extending generally in a direction of the seam, and a plurality of belt segments are mounted for lateral movement on the endless flexible portion and each having an edge adapted to contact one of the plates below the horizontal seam. The belt segments cooperate to support a layer of welding flux adjacent the seam and this flexible element is provided with driving means to move it along the seam.

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For copies of articles write directly to publications in which they appear. A list of addresses is available on request.

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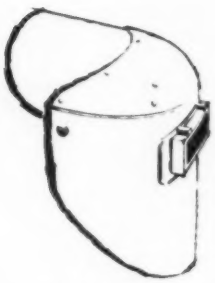

NO. 7 OF A SERIES

"How to Design Welded Aluminum Structures"

New Design Specifications for Welded

Mr. Harry N. Hill,
Engineering Design Division Chief, Alcoa Research Laboratories, Aluminum Company of America, reports findings presented at the 1959 annual meeting of the American Society of Civil Engineers.

New recommended design rules for a number of the more important aluminum alloys being welded today have been prepared by Alcoa. These rules are based on the results of continuing investigations at the Alcoa Research Laboratories and have led to the new concepts of strength of welded aluminum that have been discussed in previous articles in this series.

While *complete* design rules are not possible in this space, the table at right lists the recommended basic allowable stresses for some of the most important alloys and tempers. (Complete rules for welded structures of 5456-H321 were presented at the 1959 annual ASCE meeting. Free copies available from Alcoa on request.) Values are for the types of structures that would be designed in steel according to AREA, AASHO or similar specifications. Allowable stresses would be about 12 per cent higher when designing structures such as those done in steel according to AISC or similar specifications. Allowable stresses *can*, of course, be adjusted to *any* desired safety factor.

The recommended allowable stresses are based on minimum mechanical properties and conservative values of minimum expected weld strength, as discussed in earlier articles in this series. Higher allowable stresses may be justified where a given welding technique gives consistently higher weld strengths.

A brief examination of the table reveals that the evaluation of the allowable stress expressions requires only the simplest arithmetic. Nomographs, such as Fig. 1 for alloy 6061-T6, make such evaluation even easier.

Allowable stresses given in the table for compression, and for shear in plates and webs, are for cases in which buckling is not involved. If strength is controlled by buckling, allowable design stresses are obtained from families of curves such as those shown in Fig. 2 for welded 6061-T6 columns and beams. Similar Alcoa charts give design stresses for buckling of plates and webs.

The final article of this series will discuss the fatigue strength of welded joints in aluminum alloys.

For top-quality aluminum welding products such as consumable electrodes, welding and brazing rods and fluxes, and solder and soldering fluxes, contact your nearest Alcoa sales office. For complete information on "Designing Welded Aluminum Structures," write Aluminum Company of America, 1762-G Alcoa Building, Pittsburgh 19, Pa.

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Developed by Alcoa Aluminum Alloy Structures

Recommended Allowable Stresses for Welded Aluminum Structures

Factor of Safety on Yielding=1.85
Factor of Safety on Ultimate Strength=2.20
Stresses are in kips per square inch

Alloy and Temper	Filler Alloy	Product	TENSION	COMPRESSION	SHEAR			
					(Plates and Webs)†		Fillet Welds	
			Beams and Members Under Axial Load	(Beams and Members) (Under Axial Load)†	Welded	Not Welded	Longitudinal	Transverse (Symmetrical)
5456-H321	5556	Sheet and Plate	$17.8-7.6\frac{A_{rt}}{A}-3.8\frac{A_{rt}}{A}$	$17.2-7.0\frac{A_{rt}}{A}-3.2\frac{A_{rt}}{A}$	8.1	10.3	9.1	14.5
5456-H343	5556	Sheet	$22.2-11.9\frac{A_{rt}}{A}-8.1\frac{A_{rt}}{A}$	$21.1-10.8\frac{A_{rt}}{A}-7.0\frac{A_{rt}}{A}$	8.1	13.0	9.1	14.5
5456-H311	5556	Extruded Shapes	$13.5-3.2\frac{A_{rt}}{A}-1.1\frac{A_{rt}}{A}$	$11.9-1.6\frac{A_{rt}}{A}-0.5\frac{A_{rt}}{A}$	7.0	7.6	9.1	14.5
5454-H34	5554	Sheet and Plate	$15.7-9.2\frac{A_{rt}}{A}-7.0\frac{A_{rt}}{A}$	$14.6-8.1\frac{A_{rt}}{A}-5.9\frac{A_{rt}}{A}$	4.9	9.2	6.4	8.6
5454-H311	5554	Extruded Shapes	$10.8-4.3\frac{A_{rt}}{A}-2.1\frac{A_{rt}}{A}$	$9.7-3.2\frac{A_{rt}}{A}-1.6\frac{A_{rt}}{A}$	4.9	5.9	6.4	8.6
5086-H34	5556	Sheet and Plate	$18.4-10.8\frac{A_{rt}}{A}-8.1\frac{A_{rt}}{A}$	$16.8-9.2\frac{A_{rt}}{A}-6.5\frac{A_{rt}}{A}$	5.9	10.8	9.1	12.3
6061-T6	5556	Sheet, Plate, Extruded and Rolled Shapes	$18.9-13.0\frac{A_{rt}}{A}-10.8\frac{A_{rt}}{A}$ or $17.3-7.3\frac{A_r}{A}$ *	$18.9-13.0\frac{A_{rt}}{A}-10.8\frac{A_{rt}}{A}$	4.9	10.8	9.1	9.1

A=Net area of cross section A_{rt}=Reduced-strength area of cross section due to longitudinal welds A_{rt}=Reduced-strength area due to transverse or localized welds
$A_r=A_{rt}+A_{rt}$

† When strength is not controlled by buckling

* Use whichever value is lower

FIGURE 1

ALLOWABLE TENSILE STRENGTHS FOR 6061-T6

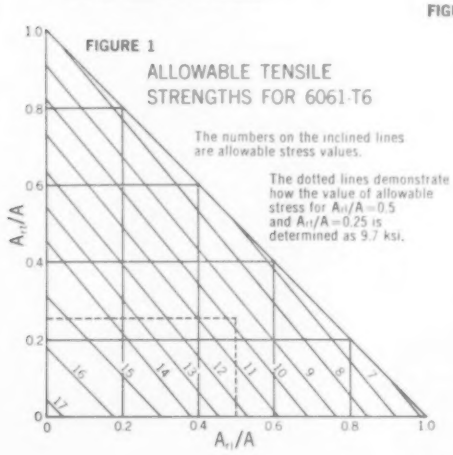
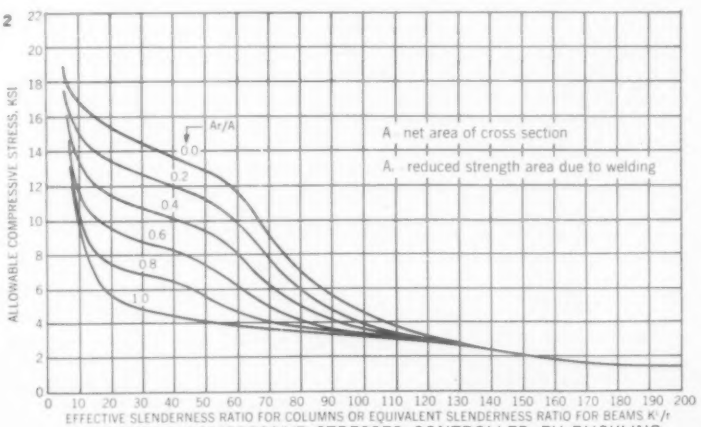


FIGURE 2


ALLOWABLE COMPRESSIVE STRESS, KSI
A_r/A
0.0
0.2
0.4
0.6
0.8
1.0
A = net area of cross section
A_r = reduced strength area due to welding
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200
EFFECTIVE SLENDERNESS RATIO FOR COLUMNS OR EQUIVALENT SLENDERNESS RATIO FOR BEAMS $K\ell/r$

ALLOWABLE COMPRESSIVE STRESSES CONTROLLED BY BUCKLING, FOR WELDED COLUMNS AND BEAMS OF ALLOY 6061-T6

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New Literature

AWS Bibliographies, 1959 Supplement Available

The AMERICAL WELDING SOCIETY has published the 1959 Supplement to the AWS Bibliographies. The original publication contains bibliographies of articles which appeared in the WELDING JOURNAL from 1937 through 1957 and each year a supplement is compiled listing the previous year's articles.

The Bibliographies previously issued list articles under 28 subject headings. The current Supplement contains similar listings of all articles appearing in the WELDING JOURNAL from January through December 1959. The complete Bibliographies thus provide a record of articles on welding, welding research and related subjects which have appeared in the SOCIETY's magazine from 1937 through 1959.

The Supplement has been designed for use as issued or as supplementary material to bring previously issued AWS Bibliographies up to date. The format is identical and entries under a given subject are contained on one or more pages. Each page is punched to facilitate insertion into the original Bibliographies under the respective subject headings.

The compilation of these data is performed as a service to industry to eliminate the time consuming examination of technical literature in the search for information on a given subject.

Copies of the 1959 Supplement to the AWS Bibliographies may be obtained at a cost of $1.50 from the AMERICAN WELDING SOCIETY, Department T., 33 W. 39th St., New York 18, N. Y.

Carbon-arc Welding

A 12-page vest-pocket manual describing the technique used for various applications of their twin-electrode carbon-arc welding torch is offered by The Arcair Co., P.O. Box 431, Lancaster, Ohio.

For your free copy, circle No. 51 on Reader Information Card.

Welding-machine Catalogs

Two catalogs have been issued by Miller Electric Manufacturing Co., Appleton, Wis. A 12-page brochure (SR-160) covers the technical details of design, manufacture and use of the company's selenium rectifiers. The second offering (WL-4-60) covers the full line of Miller machines, illustrating and describing some 40 different models.

For your free copy, circle No. 52 on Reader Information Card.

Welding-rod Data Sheets

Data sheets giving the complete characteristics of 6 of their filler rods are available from National Cylinder Gas Div., Chemetron Corp., 840 N. Michigan Ave., Chicago 11, Ill.

The types covered are: NCG 120, Stainless Steel, Type 347 (N-1030); NCG 3110, Aluminum, Type 1100 (N-103Q); NCG 3112, Aluminum, Type 4043 (N-103R); NCG 718, Aluminum (N-103S); NCG A-54-S, Aluminum Type 5154 (N-103T); and NCG C-56-S, Aluminum, Type 5356 (N-103U).

For your free copy, circle No. 53 on Reader Information Card.

Bronze Electrodes

The first Quarter 1960 issue of "Ampco Welding News" covers applications of bronze-alloy welding rods and describes a number of extruded forms available. Ampco Metal, Inc., 1745 S. 38th St., Milwaukee 46, Wis.

For your free copy, circle No. 54 on Reader Information Card.

Cryogenic Couplings

Transition couplings of new design, used in the fabrication of dewars and other cryogenic equipment, are described in a 4-page bulletin issued by Project Fabrication Corp., 112-20 Fourteenth Ave., College Point 56, N. Y. The couplings feature a stainless-aluminum bonded structure without gaskets or flanges.

For your free copy, circle No. 55 on Reader Information Card.

Alloy News

The March-April, 1960, issue of "Colmonoy Alloy News" features various types of surfacing methods and the characteristics of the bonded metals. Published by Wall Colmonoy Corp., 19345 John R. St., Detroit 3, Mich.

For your free copy, circle No. 56 on Reader Information Card.

Practical Preheat Method

Available from J. B. Nottingham & Co., Inc., 441 Lexington Ave., New York 17, N. Y., is a 4-page bulletin featuring the DurElec "building-block electrical strip-heater system" for preheat during welding. Time-saving advantages, satety, control of preheat and installation methods are described.

For your free copy, circle No. 57 on Reader Information Card.

Ceramic Welding Cups

Diamonite Products Mfg. Co., Shreve, Ohio, offers descriptive catalogs on their line of alumina welding cups, nozzles and special ceramic shapes.

For your free copy, circle No. 58 on Reader Information Card.

Arc-welding Guide

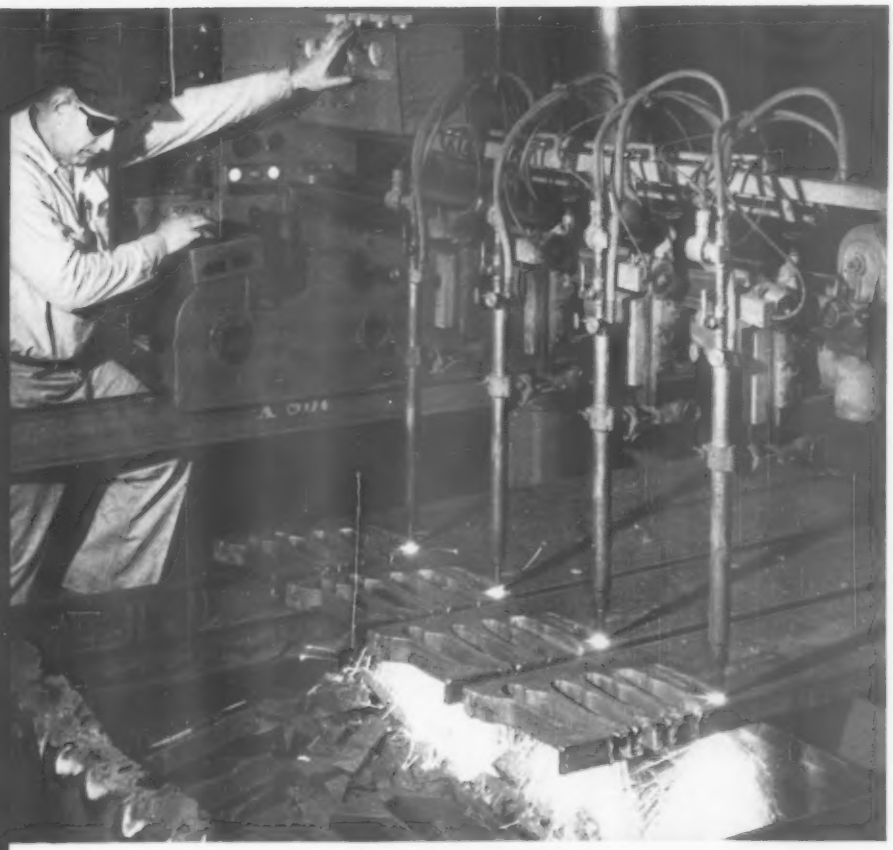
"Vest Pocket Guide to Better Welds," a revised edition of "How to Get Better Welds," contains 80 pages of arc-welding information and is available from Hobart Brothers Co., Troy, Ohio.

The $6^1/_2 \times 3^3/_4$-in. booklet gives handy information on welding essentials and proper welding procedures.

For your free copy, circle No. 59 on Reader Information Card.

DON'T SPEND MONEY— MAKE MONEY... WHEN YOU BUY OXYGEN CUTTING MACHINES

WELDING ENGINEERING · Messer · SINCE 1898 ·



AMF Estimates Messer Statosec Will Pay For Itself In 18 Months!

Yes, American Machine and Foundry, Brooklyn, has achieved results far beyond expectations from the Messer oxygen cutting machine shown here. This *Statosec* unit turns out dies (for cigar wrappers) at a rate far faster than they were formerly produced.

Cost savings are such that the Messer machine can pay for itself in only 18 months—a factor that can contribute substantially to profits.

Don't spend money, make money by installing Messer machines.
Write for details on the complete Messer line.

Messer Cutting Machines, Inc.

CHRYSLER BUILDING • 405 LEXINGTON AVENUE, NEW YORK 17, N.Y.

In Canada: Liquid Carbonic Canadian Corporation, Montreal

For details, circle No. 24 on Reader Information Card

Two Catalogs Update Welding Equipment

Air Reduction Sales Co., 150 E. 42nd St., New York 17, N. Y., has published revised catalogs on their complete line of Aircomatic and Heliweld processes.

Recently introduced equipment in the Aircomatic (gas-shielded metal-arc) line includes a CO_2 manual gun and two machine heads, as well as accessories (catalog ADC 717 F).

The Heliweld (tungsten inert-gas process) equipment is covered in a 24-page booklet (ADC 709G) that includes a packaged manual welding outfit, two new automatic welding heads and two new manual holders.

For your free copy, circle No. 60 on Reader Information Card.

Temperature-conversion Chart

The April 1960 issue of "Fansteel Metallurgy" has a short article on cladding and bonding refractory metals. Included with the issue is a loose page having a 6-in., °C–°F temperature-conversion dial on one side; on the other, 35 physical properties are listed for W, Ta, Mo and Cb. Fansteel Metallurgical Corp., North Chicago, Ill.

For your free copy, circle No. 61 on Reader Information Card.

Practical Welding News

"The Lincoln Stabilizer" vol. 29, no. 1, is a 20-page news magazine covering dozens of items of value to practical men who are interested in welding. Featured are success stories in welding, numerous practical tips and hints, ingenious solutions to problems, new designs made possible by welding and the adaptation of welding to new equipment and repair in industry, the farm and the home. Published by Lincoln Electric Co., 22787 St. Clair Ave., Cleveland 17, Ohio.

For your free copy, circle No. 62 on Reader Information Card.

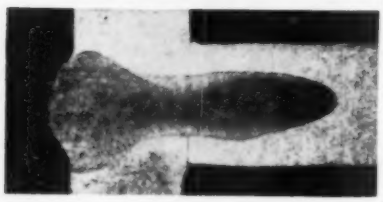
Nuclear-piping Brochure

Facilities for the fabrication and erection of critical piping for the nuclear age as well as their facilities for manufacturing welding fittings for nuclear piping systems are described in a 24-page bulletin issued by Midwest Piping Co., Inc., 1450 S. Second St., St. Louis 4, Mo.

Titled "Critical Piping for the Nuclear Age," the illustrated booklet shows operations at Midwest's manufacturing and fabrication plants during production of welding fittings and fabricated assemblies for nuclear installations.

For your free copy, circle No. 63 on Reader Information Card.

Who said: "Un-weldable?"



Before you call it "un-weldable" check it out on the NRC Electron Beam Welder. Problems posed by reactive metals, dissimilar materials, heat sensitivity, and unusual geometry are being solved daily.

•Tungsten, tantalum, columbium, zirconium, etc. are welded free of contamination and porosity • Finish machined parts are joined without distortion • Sensitive instruments are evacuated and sealed • Precision welds are made at the bottom of a 1/16" slot or between two surfaces meeting at an acute angle • Depth/width ratios greater than 4/1 are attained.

Try NRC E B Welding . . . a special Small Lot Welding Service is available at hourly rates, or you can get a complete E/B installation for less than $16,000! Call or write now.

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Dept. J-6,
160 Charlemont St.,
Newton 61, Massachusetts
DEcatur 2-5800

NRC EQUIPMENT CORPORATION

For details, circle No. 25 on Reader Information Card

Welded Interstate Highway Bridges. Edited by James G. Clark. The James F. Lincoln Arc Welding Foundation, Cleveland, Ohio. 269 pp., approx. 6 × 9 in. Price $2.00 in USA, elsewhere $2.50.

This informative book sets forth the details of the 16 winning designs of the 1958 contest sponsored by The James F. Lincoln Arc Welding Foundation and entitled "Welded Bridges for Interstate and Defense Highways." The bridge competition was the fourth of its kind held by the Foundation whose numerous educational activities have played a major role in popularizing real advantages achieved by welded designs. The awards, which carried stipends totaling $50,000, were made on the basis of the specification conditions, engineering detail, economy and appearance. Considered practical and of wide application, the realistic approach is borne out by the fact that many of these bridges have been built while some others are in the process.

The winning entries are grouped by types under four chapter headings: Plate Girders, Arches, Box Girders and Bascule. Each presentation is preceded by an interesting rationale of design followed by numerous reduced-scale drawings showing the superstructures in comprehensive detail.

•

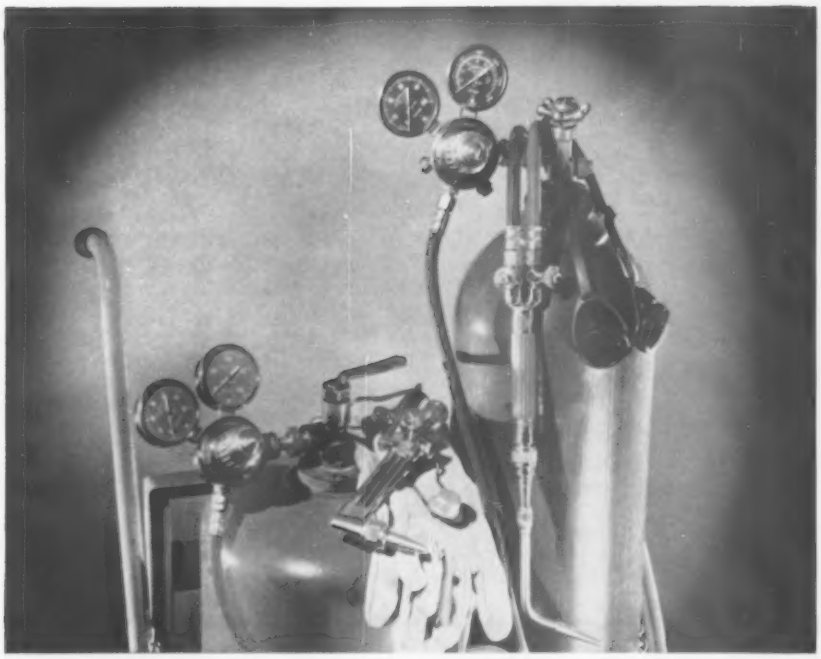
Foreign Books. Reviews obtained from foreign periodicals by Gerard E. Claussen, contributor of World-Wide Welding News.

Thermit Welding (Die Aluminothermische Schweissung) by W. Gunther and F. Proschek, 184 pages, 131 figures, 14 tables; published by Carl Marhold Verlag, Halle (Saale), East Germany 1959, 20.95 marks.

This is the first of three volumes to be published on thermit fusion welding. The first volume discusses the physical chemistry of the process, the properties of welds and the application of thermit welding. The second and third volumes will deal with rail welding and with general repair work. The authors are associated with the Central Welding Institute in East Germany and with Elektrochemisches Werk Ammendorf.

Among the interesting details of preparation of raw materials for thermit welding is the care taken to prevent access of moisture to the aluminum, in this way avoiding hydrogen porosity. The scale for the reaction should analyze 12 to 16% Fe (2+), this content being achieved by heating in an oxidizing atmosphere at 1750° F. Entrapment of metal in the slag may be prevented by adding 5% fluorospar to the charge.

The book contains numerous photomicrographs of rail welds and results of fatigue tests on thermit welded rail. The application of the process to pipe, concrete reinforcing bars and aluminum and copper cable is described. Thermit pressure welding is not discussed.



lasting quality saves more than merely a low price!

it's how long it serves you that determines your cost

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our customers rarely change to other makes ● ● ●

BECAUSE: their own experience proved that the fifty years of our experience in the welding and cutting fields assured them highest quality with years of satisfying and trouble free service.

We originated the solid bar stock regulator body — eliminated the metallic feel of the tension screw action and made it accurate and smooth — perfected the multiple nozzle mixer for greater saftey and better performance.

your money buys no finer equipment—

Your confidence built our business. *Write for descriptive literature, or the name of our nearest distributor.*

555 DEPT.

NATIONAL welding equipment company...

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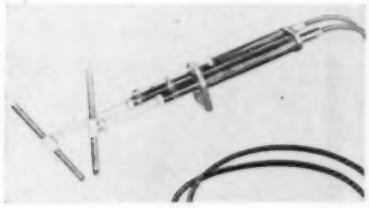
50 National of ...california

For details, circle No. 26 on Reader Information Card

New Products

Twin Carbon-arc Torch

Metal and Thermit Corp., Rahway, N. J., has added to its line an a-c torch which uses the heat from the arc of twin carbon electrodes.

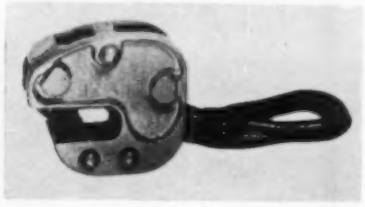


The torch is intended for welding, brazing, hard surfacing, soldering, preheating or general heating.

For details, circle No. 101 on Reader Information Card.

Short-leg Clamp

A handling device, known as the Merrill 2-ton structural clamp, was designed with a "short leg" feature in order to provide a secure bite on

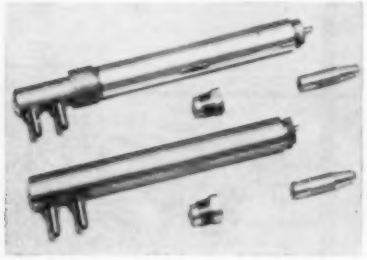


small junior-size beams, eliminating time lost in slinging. Merrill Brothers, Artic St., Maspeth, N. Y.

For details, circle No. 102 on Reader Information Card.

Spot-welding Tip Holders

A line of straight resistance-welding tip holders has been introduced by Air Reduction Sales Co., 150 E. 42nd St., New York 17, N. Y. The holders are of two types. The nonejector type is trade-named "Goldspot." The ejector type, named "Goldcrown," utilizes a new method of tip ejection.



For details, circle No. 103 on Reader Information Card.

Magnetic-particle Testers

Two magnetic-particle testing units said to provide economical detection of tiny flaws as deep as 1/2 in. below the surface are part of a new line announced by Picker X-Ray Corp., 25 S. Broadway, White Plains, N. Y.

One unit is stationary, the other

mobile. The stationary unit, called the Ferroscope, is said to provide sensitive inspection for maintenance work, quality control and production runs of small parts. It has 6000-amp, d-c output and meets Mil-1-6867A Type II equipment specifications.

The mobile Ferroscope is used to find defects primarily on large rough parts that must be checked on the spot. The mobile unit has a 3000-amp output for both a-c and half-wave d-c outlets.

For details, circle No. 104 on Reader Information Card.

Twin Carbon Electrodes

The model B-3 Twin Electrode Torch made by Arcair Co., P.O. Box 431, Lancaster, Ohio, is for use with any a-c welding machine.

Two cored-carbon electrodes produce an electric arc for heating, soldering, brazing and welding jobs.

For details, circle No. 105 on Reader Information Card.

Torch Cuts 30-in.-thick Metal

A natural-gas cutting torch that can slice through 30 in. of metal in a single pass has been introduced by Linde Co., Division of Union Carbide Corp. The Oxweld C-66 cutting torch is said to employ up to

3000 cfh of oxygen and 250 cfh of natural gas and to have a cutting range from sheet metal to large risers. Special applications such as gouging, rivet piercing and pad and fin washing are also said to be handled with ease.

For details, circle No. 106 on Reader Information Card.

Gas Metal-arc Welding Machine

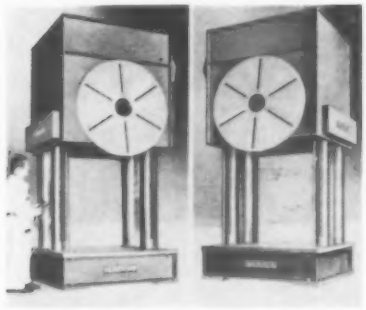
Miller Electric Mfg. Co., Inc., Appleton, Wis., announces a gas metal-arc welding machine, model CP-3-VS. The company claims that perfect X-ray results are possible on aluminum, manganese, stainless and carbon steel sheets down to a thickness of 0.030 in.

The new model is also said to provide continuous slope and voltage adjustment while welding, between the limits of 300 amp at 30 v and 25 amp at 10 v.

For details, circle No. 107 on Reader Information Card.

Head and Tail-stock Positioners

Now being manufactured by Aronson Machine Co., Inc., Arcade, N. Y., are heavy-duty geared elevation head and tail-stock positioners used for positioning weldments such as freight and piggyback cars for down-hand welding. Low horizontal axis keeps weldment near



floor, while elevation feature enables clearance for indexing. All models have a hollow spindle to allow for the passage of cables, gases or fixturing and have a full complement of accessories to facilitate various applications. Capacities are from 6 to 120 tons.

For details, circle No. 134 on Reader Information Card.

Flux in Flame

A Liquiflux for brazing and welding has been developed by Rexarc, Inc., West Alexandria, Ohio. The product—Cast Iron Liquiflux—enables continuous brazing operations without the necessity of painting the metal with powdered flux, and without dipping the welding rod into powdered flux. The flux is vaporized and inducted into the gas stream automatically, as required, and passes through the welding torch into the flame. Wherever the flame goes, there is automatic fluxing. No special torch is needed, according to the manufacturer.

Developed primarily for brazing brass to cast iron, and cast iron to steel with brass, the product is a solvent for the oxides on most cast irons, and greatly facilitates the flow of chrome alloys, and chrome, cobalt and tungsten alloys applied to steel or cast iron.

For details, circle No. 108 on Reader Information Card.

Spray Cans for Magnetic-particle Testing

A development by Magnaflux Corp., 7300 W. Lawrence Ave., Chicago 31, Ill., is the convenience of magnetic-particle inspection materials available in pressurized spray-cans and plastic squeeze-bot-

tles. These materials can be used with any of the equipment or test kits already in operation.

According to the manufacturer, the ready-to-use Magnaflux-Magnaglo materials eliminate previous bulky containers, and the problems of mixing to formula, or filling application devices, and reduce set-up time to inspect complex parts. The new sealed dispensers keep out dust, moisture and other contamination during storage.

For details, circle No. 109 on Reader Information Card.

Cotton Welders Clothing

Protection plus comfort in inert-gas arc welding, and where flame or solder splashes are present, are offered by Singer Glove Mfg. Co., 860 W. St., Chicago 22, Ill.

Welders clothing made of flame-resistant finely woven cotton twill cloth, in black, are said to cost less than half the leather type.

For details, circle No. 110 on Reader Information Card.

Automatic-welding Flux

Autoflux H-950 is an inert automatic-welding flux developed for use with automatic submerged-arc hard-surfacing wires and supplied by Hobart Bros. Co., Troy, Ohio.

It is said to be truly inert and will not cause complicated alloying effects with the deposited weld metal. Hardness, ductility and work hardening characteristics of the weld metal will be determined only by the alloying content of the wires when using this flux.

For details, circle No. 111 on Reader Information Card.

BATEMAN
BANTAM
IRON WORKER

THE ONLY IRON WORKER OF ITS KIND ON THE MARKET TODAY

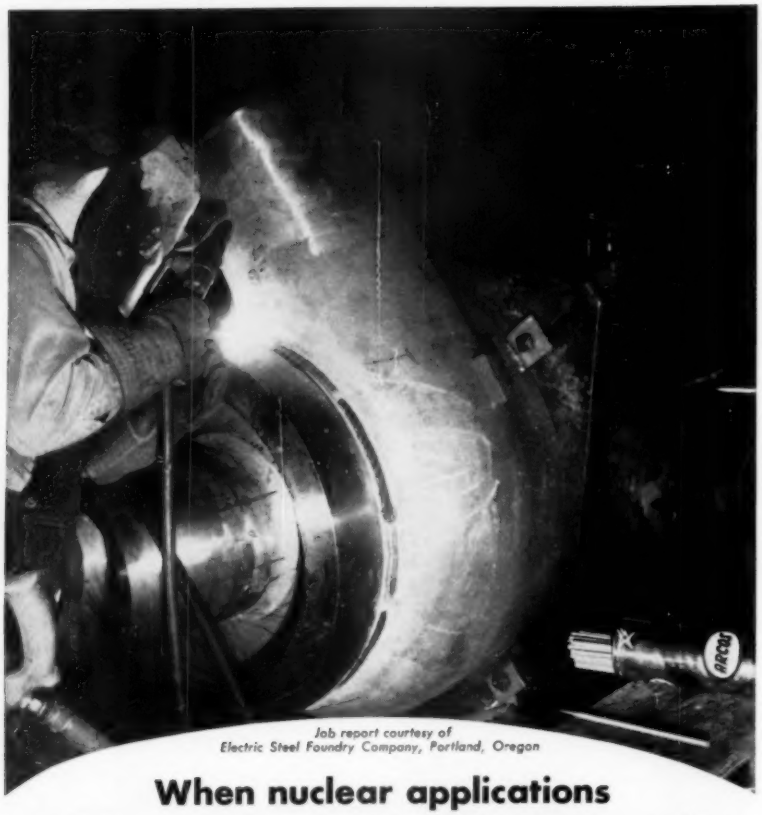
No Grinding Necessary After Cut. One Stroke Cycle Clutch Operated by Hand or Foot.

The Bateman "Bantam" cuts 2" x 2" x ¼" angles and ¼" x 4" flats. Standard punches will fit this machine. The Coper will cope 1¼" through ⅛" material. It will punch ½" hole through ¼" material. With the clutch open, the Bantam will make 44 strokes per minute. It is made of high-grade cast iron, with the clutch, pin and dog made of hardened steel. The blades are made with tool steel. It is powered with a fly wheel and gear drive, and uses a small ¼ hp motor, 1750 rpm.

Bateman Bantam with punch....$575.00
Shear only.....$495.00
Shipping wt. 750 lbs.

BATEMAN FOUNDRY & MACHINE
MINERAL WELLS, TEXAS

For details, circle No. 27 on Reader Information Card



Job report courtesy of
Electric Steel Foundry Company, Portland, Oregon

When nuclear applications call for stainless welds of highest quality

WELD WITH ARCOS

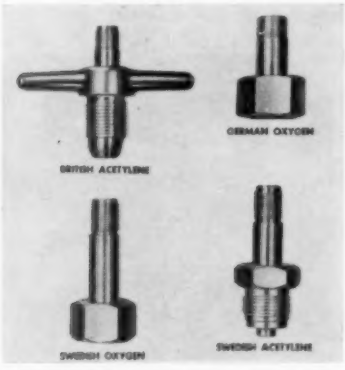
STAINLESS ELECTRODES

This is part of a 3900 lb. stainless pump-volute casting for a submarine nuclear power plant. In the photo, a skirt is being welded to the casting using 5/32" dia. Arcos Chromend K Electrodes. To minimize stresses, a step-back and skip procedure was used. These welds conformed to Class I Navy radiographic standards—an indication of the dependability of standard Arcos electrodes for your stainless welding needs. ARCOS CORPORATION, 1500 South 50th St., Philadelphia 43, Pa.

For details, circle No. 28 on Reader Information Card

Adapters for Foreign Cylinders

To facilitate the use of foreign oxygen and acetylene cylinders in the United States, the Bastian-Blessing Co., 4201 W. Peterson Ave., Chicago 46, Ill., has developed a line of adapters. German, British

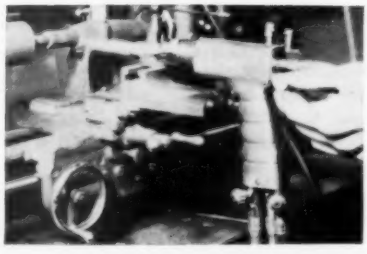


and Swedish acetylene cylinders may be adapted to standard POL or commercial connections. Oxygen adapters have the standard CGA No. 541 connection.

For details, circle No. 112 on Reader Information Card.

Metal-spray Gun

A lightweight, Spraywelder Unit which features a 12-lb/hr spray rate and a 95% efficient deposit is claimed by Wall Colmonoy Corp., 19345 John R St., Detroit 3, Mich.

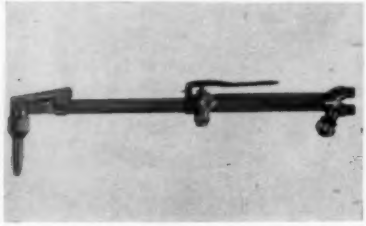


The new equipment provides 20% reduction in spray pistol weight.

For details, circle No. 113 on Reader Information Card.

Fitter's Cutting Torch

The Harris Calorific Co. of Cleveland, Ohio, offers a lightweight top-lever fitter's cutting torch.



Known as Model 42, this torch is reported ideal for one-hand operation because the cutting lever is mounted forward and on top for better grip and better balance. It is available in 3 different models: the 42 for acetylene, the 42-F for propane and the 42-N for low-pressure natural gas.

For details, circle No. 114 on Reader Information Card.

Welder's Glove

Imported Carpincho is the leather used by Singer Glove Mfg. Co., 860 West Weed St., Chicago 22, Ill., in this new line of welder's gloves. It is described as a soft, supple

leather that resists heat shrinkage better than any other leather known to the welding industry.

Another feature of the glove is the extra-wide reinforcement in the thumb crotch.

For details, circle No. 115 on Reader Information Card.

Resistor Control Units

An improved line of multiarc welding control units has been introduced by J. B. Nottingham & Co., Inc., 441 Lexington Ave., New York 17, N. Y. The new "Weldline" resistor units are available in compact, lightweight 6-, 4-, and 2-operator models.

In addition to d-c metallic-arc

Job Report Courtesy of
Ingersoll-Rand Co., Phillipsburg, N. J.

For pressure resisting high strength low alloy welds

The intake and discharge nozzle welds on this re-cycle compressor casing must provide high strength for long service life under rugged conditions. To assure sound, crack-free welds, Arcos Tensilend 70 Electrodes were used. These electrodes, especially suited for welding mild steel and low-alloy high-tensile steels, produce welds with a yield of 70,000 psi in the *as welded* condition. Use Arcos electrodes for the same dependable performance.

WELD WITH ARCOS

LOW ALLOY ELECTRODES

for quality weld metal

ELECTRODES • WIRE • FLUXES
SEMI-AUTOMATIC AND AUTOMATIC EQUIPMENT FOR WELDING
STAINLESS • LOW ALLOY • ALUMINUM • MILD STEEL

ARCOS CORPORATION, 1500 South 50th Street, Philadelphia 43, Pa.
For details, circle No. 29 on Reader Information Card

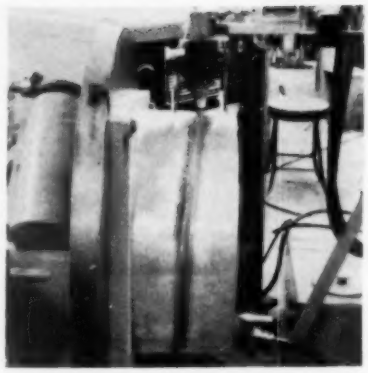
welding with coated electrodes in all positions, the units may be used for other types of electric arc welding, including the gas-shielded tungsten-arc and consumable-electrode processes. Switches on the front of each drawer in the unit make it easy for each operator to vary the current in steps as small as 1 amp for accurate welding control.

For details, circle No. 116 on Reader Information Card.

Electronic Seam Tracer

As an additional feature that can be used with its controlled-arc-length automatic welding equipment, an electronic seam tracer is offered by the Weldma Co., 62 La-Salle Rd., West Hartford 7, Conn.

In operation, an electronic feed-back circuit senses a change in potential difference as the welding arc migrates in a small neighborhood at the joint. Crossing the joint changes the polarity of the signal. The servo-mechanized system operates to nullify the error signal and thus returns the electrode to its predetermined position with respect to the joint. A small, continuous error signal is required by the feed-back circuit which makes it necessary to operate the electrode slightly off the centerline of the joint.

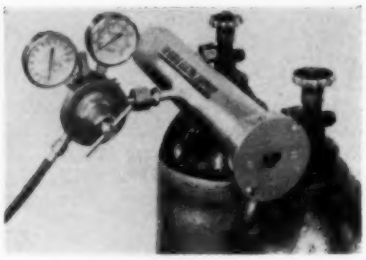


Among other advantages, this device is said to make possible the welding of parts not observable by a welding operator, such as in missile cases or other long cylindrical workpieces.

For details, circle No. 117 on Reader Information Card.

Heated Manifolds

Electrically heated CO_2 manifolds, said to prevent regulator freeze-ups while helping cut gas consumption during welding operations, have been developed by the World Electric Co., 4614 Prospect Ave., Cleveland 3, Ohio. Available



for two- and four-bottle systems, both manifolds are self-contained, one-piece units designed to work with any set of standard regulators, and come equipped with all necessary fittings, gaskets and electrical wiring. Heating is accomplished by an electrical element built right into the manifold.

For details, circle No. 118 on Reader Information Card.

NOW
SPEAK
They mean National Carbide's calcium carbide—Real potent... it's hot-crushed!
All you want—when you want it. In the RED DRUM. Wire for supplier...
NATIONAL CARBIDE COMPANY
A DIVISION OF AIR REDUCTION COMPANY, INC.
150 East 42nd Street, New York 17, N.Y.

For details, circle No. 30 on Reader Information Card

Butt-welding Machine

Peer, Inc., 1200 Milton St., Benton Harbor, Mich, announces a high-production, precision butt-welding unit. The new Model B10 is an automatic air-operated butt welder with clamping jaws and upset pressure air-operated by independent air cylinders giving control of the degree of upset. Several other features are said to simplify

and improve the operation for which it is only necessary to set the jaw clamps for the thickness of material being welded, set the current control switch for the degree of heat required and start welding.

For details, circle No. 119 on Reader Information Card.

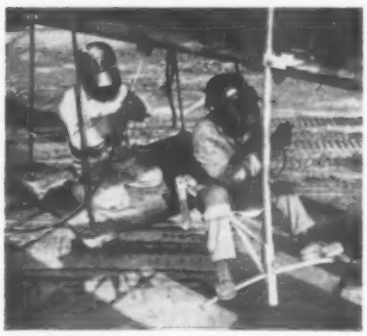
Superior Adds New Line

M. J. Ward, president of Superior Electronics Services Co., Inc., with offices at 3810 Chicago Ave., Minneapolis, announces a new line of resistance spot welding machines, to be known as "Weld-Rite," and manufactured in Minneapolis by Superior Electronics.

For details, circle No. 120 on Reader Information Card.

Welders Bosun Chair

Safety, convenience and ease of adjustment are the features of a tubular steel "sulky" for welders on bridge girders and other overhead structures. It was designed to replace the old-fashioned wooden float or platform slung on ropes as shown in the illustration. It should



be of interest to engineers, contractors and fabricators active on the many new superhighway bridges now being erected.

The telescopic sulky comprises a simple pressed steel perforated seat protected by a 9-in. high circular rail of steel strapping. Support for the seat is welded steel scaffold tubing and it carries a curved tubular footrest. This entire assembly rides a tubular steel mast which is hung on a bracket straddling the top flange of the girder. The mast is punched at 12-in. intervals to permit the sulky to be pinned to it at any desired level for the most convenient welding position. The unit weighs 45 lb and is manufactured by P. H. Mallog Co., Niles, Ohio.

For details, circle No. 121 on Reader Information Card.

X-ray Film-badge Service

A wristband film-badge holder for checking radiation dosage comes with space for two films: one for weekly check and one for the 13-week check. The manufacturer, St. John X-Ray Laboratory, Califon, N. J., offers complete service as well as information as to requirements.

For details, circle No. 122 on Reader Information Card.

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For details, circle No. 31 on Reader Information Card

Low-load Testing Machine

Interchangeable "load cells" are a unique feature of the model LPT testing machine just announced by Detroit Testing Machine Co., 9390 Grinnell Ave., Detroit 13, Mich. Designed to perform all manner of

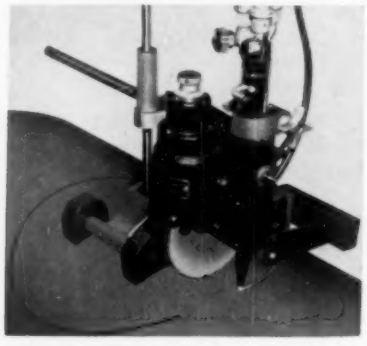
tensile and compression-strength tests within its relatively low-load capabilities, it allows the use of four different load cells, each providing a different maximum load (100, 200, 600, and 1,000 lb) with gages and graduations to match.

Tensile test specimens up to $^{3}/_{16}$-in. thick, 1 in. wide and 12 in. long and compression test specimens up to 4 in. diam and 6 in. high are said to be accommodated.

For details, circle No. 123 on Reader Information Card.

Mechanized Torch

A mechanized hand cutter for pipe, tank and plate fabricators is offered by Steffan Manufacturing Corp., P.O. Box 275, Salem, Ohio.

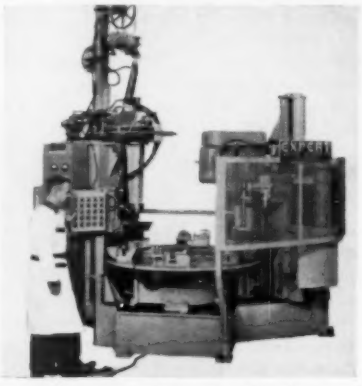


Designed primarily for cutting round openings in tanks and large diameter pipe, the machine makes straight, irregular or circular cuts in flat plate with equal speed and accuracy. Weight is 23 lb.

For details, circle No. 124 on Reader Information Card.

Automated Welding Machine

A 6-station rotary-index automated welding machine that combines assembly, CO_2-shielded arc-welding, reaming and spot-facing



operations in the production of motor-mount brackets is available from Expert Welding Machine Co., 17144 Mt. Elliott Ave., Detroit 12, Mich. With this automated welding concept, part production costs are substantially reduced as a number of operations are combined in one machine. Production rate is 360 parts per hour.

For details, circle No. 125 on Reader Information Card.

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Zváračský sborník

Czechoslovak technical journal for welding and allied proceedings

The journal publishes especially the results of Czechoslovak welding research, as well as lectures held on the occasion of international welding congresses arranged by the Slovak Academy of Sciences, the Scientific-Technical Society and the Welding Research Institute. The articles are determined for research workers and a considerable part of same deals with theoretical problems. The articles are being published in Slovak and Czech language with additional, detailed summaries in English, German and Russian language.

Further, many prominent specialists from abroad have their works published in our journal.

The editorial staff has its seat at the Welding Research Institute in Bratislava. Editor-in-chief is the well-known Czechoslovak welding specialist Prof. Dr. Ing. Joseph Čabelka.

The quarterly, comprises 128 pages, at the price of US $5.20.

Subscriptions, inquiries address to your local news agent or directly to **ARTIA, Praha, Czechoslovakia**.

Brazing Machines

Designed primarily to take advantage of the rapid brazing rates of silver alloys, mechanized brazing machines are reported by Boyd

Welding Co., 160 E. 8th St., Erie, Pa. With their use, savings of over 300% are said to have been initiated.

For details, circle No. 126 on Reader Information Card.

Magnetic-particle Tester

A magnetic-particle testing device weighing 24 lb is offered by Laboratory for Nondestructive Testing P.O.B. 1056, Stn. B, Montreal 2, Canada. Exchangeable pole

pieces are said to make possible the testing of circumferential welds, fillet welds and butt welds up to $^3/_8$ in. thick.

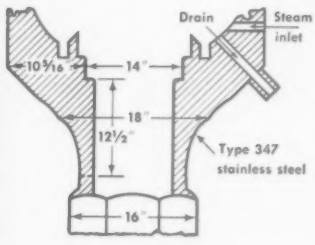
For details, circle No. 127 on Reader Information Card.

Self-fluxing Brazing Alloy

A copper-phosphorus alloy that does not require flux on copper-to-copper joints is now available from American Brazing Alloys Corp., P.O. Box 11, Pelham, N. Y. It starts to melt at 1300° F and has a wide brazing range. This general purpose alloy, called Phos Sil O, finds use on copper, brass, bronze and other alloys and conforms to AWS specification BCuP-2 and Federal specification QQB-00655A.

For details, circle No. 129 on Reader Information Card.

Profit through E.A.I. Research



Uniform, through-and-through heating of the thickest sections of the big stainless steel valves was provided by the Smith-Dolan method, with precision control of temperatures (2-hour dwell at 1900°F.). Drawing shows cross-sectional dimensions.

Standard Smith-Dolan units come equipped with eye hooks and wheels for easy portability, and with instrumentation for recording permanent charts of the heat run.

SMITH-DOLAN
On-the-Job HEAT TREATMENT

Solution to Weld Embrittlement Problem at Consolidated Edison

Public utilities are among the largest users of the Smith-Dolan System of Low-Frequency Induction Heating. They want to keep their service uninterrupted, their costs low, and they find that this portable system simplifies the problem of pre-heating and post-annealing in producing sound welds, and in making dependable repairs.

A typical application of the system by a public utility was described in a recent article in Welding Design & Fabrication.* At Consolidated Edison's No. 10 Turbine Generating Station in New York City, two large steam pressure valves made of Type 347 stainless had to be repaired because of weld embrittlement. Removal to the shop for heat treatment would have proved costly and time taking. With the Smith-Dolan portable units, the work was completed on the job within 12 hours.

Learn about the savings and other benefits your company can obtain from the Smith-Dolan System. It is today's most versatile heat treating method, simplifies and upgrades work quality in numerous applications. Write for brochure, "Smith-Dolan System of Low-Frequency Induction Heating."

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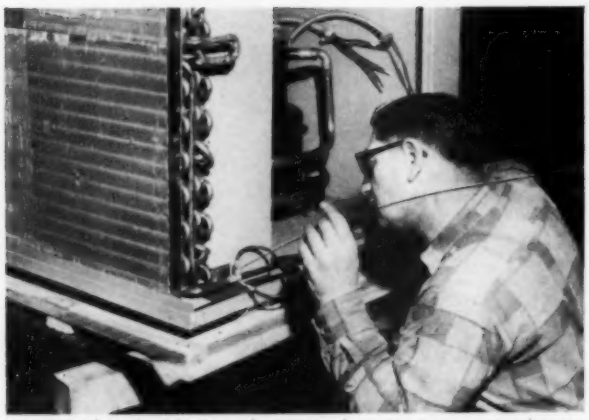
HOW TO MAKE 4,999 JOINTS WITHOUT FAIL



Here, with a double tipped oxyacetylene torch, operator brazes condenser coil joints. This condenser-compressor assembly contains 30 hook-up joints, not counting return bends.

The unit evaporator, located inside the house, contains 36 hand-brazed SIL-FOS 5 joints.

International Heater Does it With HANDY & HARMAN SIL-FOS 5

Production statistics of this manufacturer of heating and air-conditioning equipment show that perhaps one in five thousand hand-brazed joints may need touching up. This is a micrometer measurement away from absolute perfection.

One of the Utica, New York, company's products is a home air conditioner that utilizes the existing duct work of the structure's hot-air furnace. Its novelty lies in the fact that the unit's compressor and condenser are located outside the house for noise-free coolness inside the home.

The unit's evaporator is installed on top of the furnace for simple tie-in to the plant's ducting for hot-weather operation.

Shown here in production is International's Model 5-5B of 5 ton capacity.

This "joint in quantity" record is being duplicated by SIL-FOS 5 silver alloy brazing in the manufacture of heating, air-conditioning and refrigeration equipment everywhere. Its strength, air- and leak-tightness and ease of application are some of the reasons that make Handy & Harman SIL-FOS 5 brazing one of the *surest* metal joiners in existence. We'd like you to know more about SIL-FOS 5 and the job it can do for you in joining copper and copper alloys in any shape, size and complexity. Our Bulletin 20 deals with this in a complete and informative manner. A request to Handy & Harman, 82 Fulton Street, New York City 38 will bring you your copy.

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20	45	70	95	120	145
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SUPPLEMENT TO THE WELDING JOURNAL, JULY 1960

1960 ADAMS LECTURE

Higher-Strength Steels for Welded Structures

Favorable evidence of suitability of these steels for weldments designed to higher stresses has been furnished by laboratory tests

BY ROBERT D. STOUT

ROBERT D. STOUT graduated from Pennsylvania State University in 1935. He received his Master's degree in 1941 and his Ph.D. in 1944, both from Lehigh University. He joined the Lehigh engineering faculty in 1939 after serving as metallurgist at the Carpenter Steel Co., Reading, Pa.

Noted in the field of welding, in 1943 he was awarded the Lincoln Gold Medal for "conspicuous advancement of the science of welding" and in 1952 he was presented the $2000 award from the American Society of Metals for "outstanding contributions to the teaching of metallurgical engineering." In 1956 he was given the meritorious service award of the AMERICAN WELDING SOCIETY.

In the summer of 1955, Dr. Stout was an official representative at the International Institute of Welding Conference at Zurich, Switzerland, and was named to the commission to study metal behavior under welding.

At present, head of the department of metallurgical engineering at Lehigh, he is active in a number of committees of the Welding Research Council and a member of the Welding Journal Committee and Technical Papers Committee of the AWS. He is a member of Sigma Xi and Tau Beta Pi, and this year was given the David Ford MacFarland Award of the Penn State Chapter of the ASM.

Dr. Stout was recently elected Director-at-large of the AWS for the term 1960–63.

Lecture presented at the AWS 41st Annual Meeting held in Los Angeles, Calif., April 25-29, 1960.

FOREWORD. I am especially pleased to be invited to present the 1960 Adams Lecture, because the first research in welding that I undertook in 1941 was a project under the guidance of a committee led by Dr. Adams. I soon became aware and appreciative of his keen and stimulating mind. One of his favorite stories was about the engineer who was accused of failing to solve an engineering problem because his approach was "too theoretical." The real trouble, Dr. Adams would point out, was that he was not theoretical enough—that is, the theories he used were inadequate to the task. That first project was concerned with measuring and controlling cooling rates in welds, so that weld properties suitable for service could be obtained. Some of the work reported here concerns the control of base-plate properties through the cooling rates produced in heat treatment. The metallurgy of welding remains a fascinating field of work.

Introduction

While there is always considerable temptation for the design engineer and the materials engineer to use each other as whipping boys, close cooperation of the two has made it possible to meet more exacting requirements in welded structures of many types. In the chemical and oil industries, for example, new process developments depend on the application of increased pressures and wider ranges of temperature which must be withstood by the containing vessels. These new requirements can no longer be met on

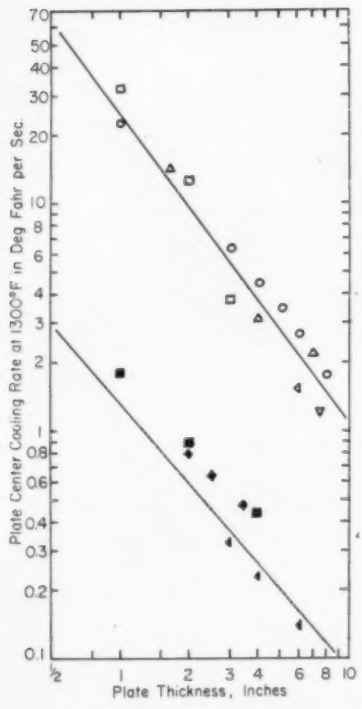


Fig. 1.—Cooling rates obtained at the center of heavy plates by normalizing or by spray quenching. Curves are averages of data from several laboratories. Upper curve, spray quenched; lower, air cooled

a practical or economical basis by carbon steels. A more sophisticated approach is to design to higher stress levels in thinner sections, which offer advantages in forming, welding and heat treatment of the steel. In this connection, the careful design of the structure to avoid unfavorable stress raisers and stress distributions, coupled with the selection of a steel which offers a suitable combination of strength and other pertinent properties, is critical to satisfactory performance.

The most troublesome task in selecting a suitable steel for a given application is to decide what set of properties is required in the steel. In addition to conventional tensile properties, certain levels of notch toughness, fatigue resistance, creep resistance or other special properties may require consideration. Low-alloy steels can furnish higher levels of these properties than carbon steels, particularly if heat treatment is used.

In this paper an attempt will be made to summarize the evidence which has been collected on the suitability of low-alloy steels for weldments designed to higher operating stresses. Most of the investigations have been sponsored by the Pressure Vessel Research Committee of the Welding Research Council.[1-4]

Acknowledgment of the contributions of the Committee members and of my colleagues at Lehigh University is here recorded gratefully.

The Bases for Selecting Suitable Steels

There are several broad and familiar principles by which to select steel types with promising characteristics for use in higher-strength weldments.

The carbon content should be kept low, preferably under 0.18%. This limit is dictated by the requirements of good weldability and adequate notch toughness. Higher carbon increases the susceptibility of the steel to porosity, weld-metal cracking and base-metal hard cracking. Carbon likewise raises the temperature range of brittle fracture, roughly 5° F for every 0.01% of carbon.

Alloying elements are used to supply the added strength required, in lieu of carbon. While many of the elements have specific effects, they share to varying degrees the ability to increase hardenability in heat-treated steels or to encourage finer and stronger microstructures in unhardened steels. Nickel and, to

Table 1—Chemical Analyses, As-received Properties and Heat-treating Temperatures of the Steels Tested

A. Chemical Analyses

Steel	Grade	C	Mn	P	S	Si	Ni	Cr	Mo	V	Other
A285	C	0.20	0.53	0.020	0.016	..	..	..	..	..	....
A201	A	0.11	0.44	0.014	0.030	0.16	..	..	..	..	....
A212	B	0.28	0.70	0.010	0.021	0.24	..	..	..	..	....
48s5HT	..	0.15	1.09	0.033	0.028	0.18	..	..	..	0.09	0.009 Ti
A203	D	0.15	0.64	0.010	0.026	0.22	3.64	..	..	..	....
A302	B	0.20	1.32	0.022	0.030	0.25	..	..	0.42	..	....
HY 65	..	0.12	0.48	0.013	0.032	0.21	2.16	..	0.39	..	0.70 Cu
NES 70	..	0.16	0.63	0.012	0.037	0.05	1.47	0.04	0.23	..	1.02 Cu
Jalloy 3	..	0.30	1.49	0.013	0.020	0.22	0.06	..	0.12	..	0.003 B
T-1	..	0.15	0.93	0.015	0.022	0.27	0.89	0.48	0.44	0.06	0.0031 B
HY 80	High	0.15	0.28	0.016	0.015	0.19	2.86	1.72	0.50	..	....
A387	D	0.11	0.37	0.01	0.010	0.26	0.16	2.20	0.96	..	....

B. As-received tensile properties and heat-treating temperatures

Steel	As-received condition	0.2% yield strength, psi	Tensile strength, psi	Elongation, in in., %	Reduction in area, %	Austenitic temperature, ° F	Stress-relieving temperature, ° F
A285	Hot rolled	...	...	..	..	1650	1150
A201	Hot rolled	29,700	54,800	33.8	65.8	..	..
A212	Hot rolled	...	...	..	..	1650	1150
48s5	Normalized	47,300	68,300	29.8	67.2	1650	1150
A203	Hot rolled	...	...	..	..	1650	1150
A302	Normalized	52,000	83,300	22.1	58.8	1650	1150
HY 65	Norm. + 1 hr, 1250° F	76,700	92,800	19.5	64.6	1750	1200
NES 70	Hot rolled + 4 hr 1100	68,700	84,600	18.1	52.9	..	..
Jalloy 3	Quenched and tempered	97,500	115,000	14.8	58.8	..	..
T-1	Quenched and tempered	114,000	123,000	13.9	57.5	1700	1200
HY-80	Hot rolled	...	...	..	..	1650	1150
A387	Annealed	...	...	..	..	1700	1350

The as-received tensile properties are reported only for those steels which were tested in that condition. Testing of as-received steels was limited largely to fatigue tests and weldability tests.

some extent, manganese, act uniquely to improve notch ductility. Chromium, molybdenum and vanadium do not raise the notch ductility, but they enhance strength and creep resistance at elevated temperatures. Phosphorous and copper can be used to retard the rate of rust formation, and copper also allows precipitation-hardening of structural steels, thus offering the possibility of raising the strength without the need of quenching.

Full deoxidation of the steel is necessary to permit the alloy specifications to be met, and also to encourage notch ductility. Aluminum killing for a fine-grained microstructure is especially beneficial to low-temperature properties, but it is not useful for properties at elevated temperatures.

The alloy content of the steel is important in connection with the degree of response of the steel to heat treatment. While normalizing improves notch ductility when it refines the microstructure, its effect is lessened as the section thickness increases. In order to obtain similar benefits in heavy sections, an accelerated cooling rate must be applied and the steel must have sufficient alloys to be responsive.

For the PVRC studies, a group of steels was chosen to cover the range of properties from those of low-carbon steel to those of a quenched-and tempered-steel of over 120,000 psi tensile strength. Table 1 contains the analysis and as-received tensile properties of the steels that were tested. Some of these steels were obtained in 4-in. thickness as well as 1-in.

The Range of Properties Available

In the final analysis, only service experience can establish the suitability of a steel for structures designed to higher stress levels. As a starting point, laboratory tests can furnish useful guidance in deciding whether to give serious consideration to such applications. Two basic groups of information are essential: (1) the mechanical properties such as tensile, notch ductility and fatigue properties that can be obtained in the steels of various thicknesses, and (2) the weldability of the steels. This section will deal with properties; the next with weldability.

Cooling Rates in Heavy Sections

Before surveying the properties which are attained in these steels, it is desirable to establish the limitations in the cooling rates that can be imposed during heat treatment of these steels as a function of the section thickness. Essentially two methods of cooling are practicable for heavy plates: air cooling or normalizing, and water-spray quenching. Normalizing is fully recognized as a desirable treatment and is even mandatory in some codes. Spray quenching, on the other hand, is known to provide strengthening and other metallurgical changes, which are not necessarily accepted to be uniformly beneficial.

Commercial quenching of large steel sections is difficult to standardize because of the many variables influencing it. Thus in the assessment of the response of the steels to heat treatment, it was decided to express the treatment in terms of cooling rate instead of the quenching technique. At the same time, cooling-rate data were collected from several sources in the hope that representative cooling rates could be assembled for the spray quenching of plates up to 10-in. thick.

Figure 1 summarizes the range of cooling rates that can be obtained in normalized and in spray-quenched plates up to 10 in. in thickness.

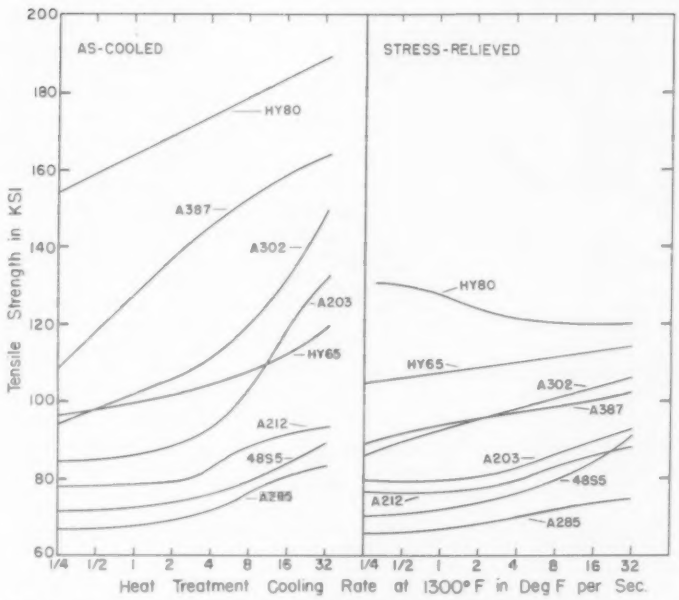


Fig. 2.—Tensile strength of steels as affected by cooling rate from austenitizing and by stress relief

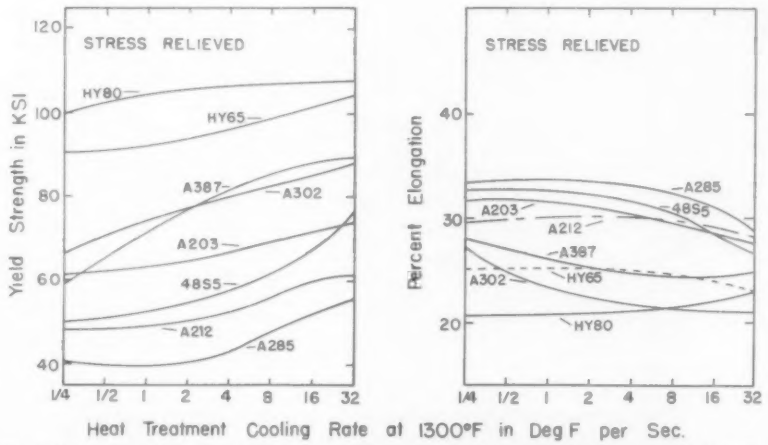


Fig. 3 (Above, left)—Effect of cooling rate from austenitizing on yield strength of steels subsequently stress relieved

Fig. 4 (Above, right)—Effect of cooling rate from austenitizing on tensile ductility of steels subsequently stress relieved

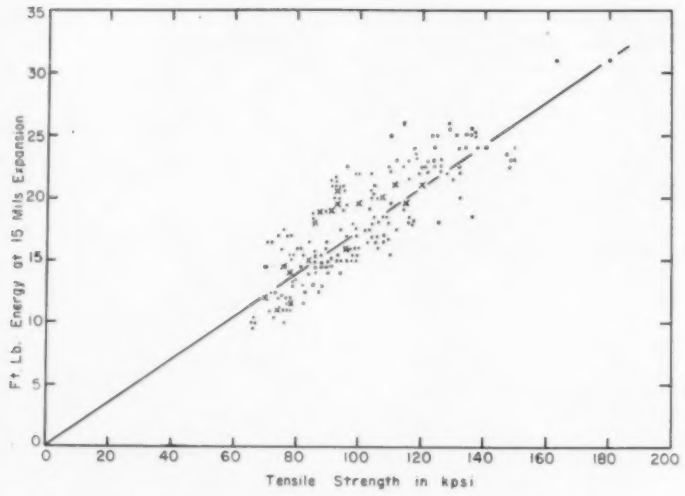


Fig. 5—Effect of the tensile strength of steel on the energy absorption in he Charpy V-notch test for constant lateral expansion

The curves indicating average values are based on Grossman H-values of quenching equal to 0.5 for spray quenching and 0.025 for air-cooling. The scatter of experimental points from various laboratories about these curves is considerable, but they represent the best information presently available. Broadly speaking, spray quenching produces a cooling rate about 15 times that of normalizing at the center of a given plate thickness. Put another way, it matches the cooling rate of a normalized plate about $^1/_8$ as thick.

Tensile Properties

Generally, the strengthening effect that can be induced in a steel by accelerated cooling treatment increases with carbon and alloy content. This is illustrated clearly by the data shown in Fig. 2, where the as-cooled plate tensile strength is found to rise sharply with cooling rate and alloy content. Only a part of the gain in strength can be retained in applications such as pressure vessels where stress relieving is specified. The need for thermal stress relief will later be shown for notch-ductility requirements. The stress-relieved values of tensile strength are shown in Fig. 2. With some exceptions, about 10% increase in strength can be retained by the accelerated cooling.

The gain in yield strength tends to be somewhat greater. Figure 3 indicates that most of the steels show about 20% higher yield strengths after accelerated cooling and stress relieving. The ductility values drop only moderately at these higher strengths, according to Fig. 4.

From examination of Figs. 2 and 3 it is evident that for section thicknesses above 4 in., accelerated cooling cannot produce a large improvement in strength. Alloying elements, on the other hand, provide uniformly higher strengths throughout the range of cooling rates.

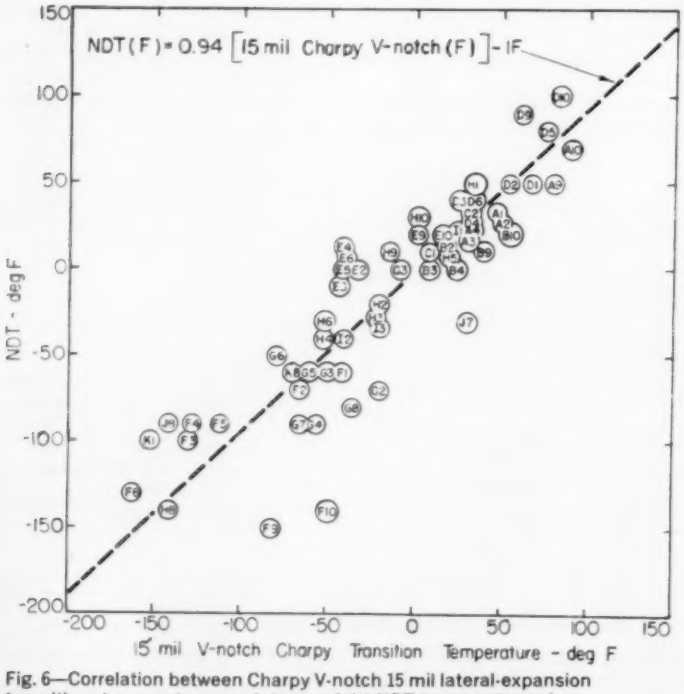


Fig. 6—Correlation between Charpy V-notch 15 mil lateral-expansion transition temperatures and drop-weight NDT temperatures for a variety of steels heat treated in various ways

Notch Ductility

While the greatest concern with resistance to brittle fracture naturally arises with service applications involving operation at temperatures below freezing, it is also important to consider the possibility of such failure during fabrication, prooftesting and down-time periods of structures normally operated at elevated temperatures. The problem of evaluating the notch ductility of materials is a knotty one, and merits some preliminary comment.

The phenomenon of brittle fracture is rather poorly understood both at a theoretical and an engineering level. For engineering purposes the most valuable function which a test can perform is to serve as an index of how suitable a material will be for a particular service. No test has yet been devised to do this. Part of the difficulty is that no firm basis exists for interpreting the test data. The best example of this is the variety of observations which are utilized from Charpy-type specimens. At one time, energy absorption values were the only data obtained from the test, but the foot-pounds specified to indicate transition to brittleness have varied from 10 to 50 ft-lb. In the last few years recommendations[5] have been made to require a certain proportion of fibrous fracture at the service temperature. Just recently investigators at Lehigh[6] have suggested that a direct ductility measurement, such as lateral expansion, is more useful than

observations of energy absorption. Even after a choice of the criterion is made, the level of performance to be specified is largely a matter of guesswork.

The assessment of the higher-strength steels for welded structures has forced a further look at the relations among the Charpy-test criteria. Analysis of service failures[7] has indicated that the 10 to 15 ft-lb level that has appeared ample for ship steel requirements must be raised for higher-strength steels. Since brittle fracture is observed to arise from a loss of ductility rather than of strength, it seems logical to measure ductility directly on the specimens and to require a chosen level of ductility, not a level of energy absorption. In Fig. 5, for example, the rise of energy absorption with tensile strength is shown for a constant ductility level, 15 mils lateral expansion. Since higher design stresses raise the elastic-energy storage in the structure, it is unrealistic to tolerate lower notch ductility in the stronger steels.

Correlation among tests is improved if the same kind of criterion is used on each. In Fig. 6 is illustrated a nearly one-to-one relation between Charpy 15-mil transition temperatures and drop-weight NDT temperatures. The inevitable scatter among test methods is noticeable in this case.

The notch ductility of the higher-strength steels has been studied as a function of steel composition and of cooling rate. Figure 7 shows the transition temperatures measured by the 15 ft-lb criterion, while Fig. 8 contains transition - temperature data according to the criterion of 15-mil lateral expansion. While the broad conclusions available from these data are not essentially different, the apparent advantage of the stronger steels is noticeably lower on a ductility basis, particularly for the as-cooled plates. The more conservative ratings shown in Fig. 8 will be accepted here for discussion purposes, but the reader can use Fig. 7 if he prefers the more conventional energy measurements.

Two outstanding points are evident in Fig. 8. First, tempering by thermal stress relieving is indispensible to obtaining optimum notch ductility in the alloy steels, regardless of cooling rate. By contrast, the carbon steels are about as good before stress relief as after. Secondly, providing thermal stress relief is applied, the higher-strength steels are considerably more notch-ductile than the carbon steels. The effect of faster cooling rates varies markedly according to the composition of the steel. The cause of this variance, which is probably microstructural, has not been established.

Thus, it is apparent that significant gains in notch ductility are possible by the use of alloy steels. In some applications this advantage may be more important than the strength level.

Table 2—Effect of Strain-raisers on Resistance to Repeated Loading Expressed as Strain-raising Factors

Steel	Plate-surface irregularities	0.01-in. deep Charpy notch	Sharp nozzle
A201	1.43	2.3	4.6
A225	1.65	3.0	..
48s5	1.48	2.8	..
A302	1.78	2.6	4.9
NES 70	1.47	2.5	..
HY-65	1.78	2.5	..
Jalloy 3	1.43	2.6	..
T-1	1.65	3.0	2.7

Fatigue Resistance

Observations of the fatigue properties of these steels was limited to a relatively low cycle life, since the

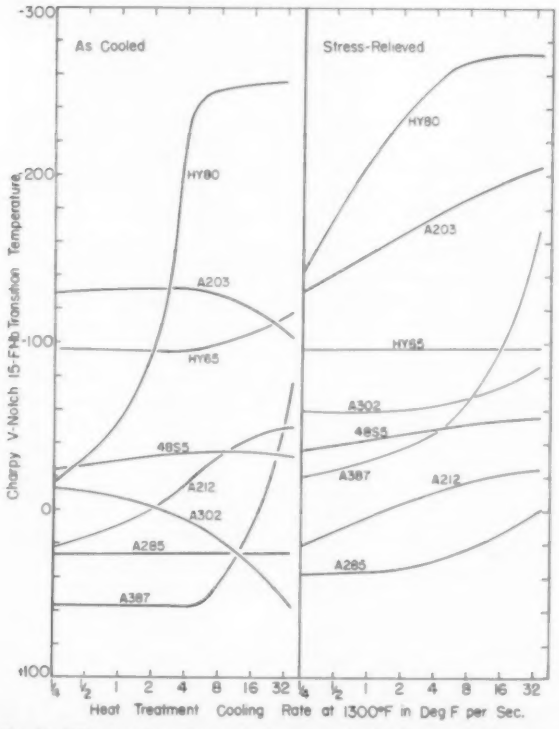


Fig. 7—Effects of cooling rate from austenitizing and of stress relief of steels on the Charpy V-notch 15 ft-lb transition temperatures

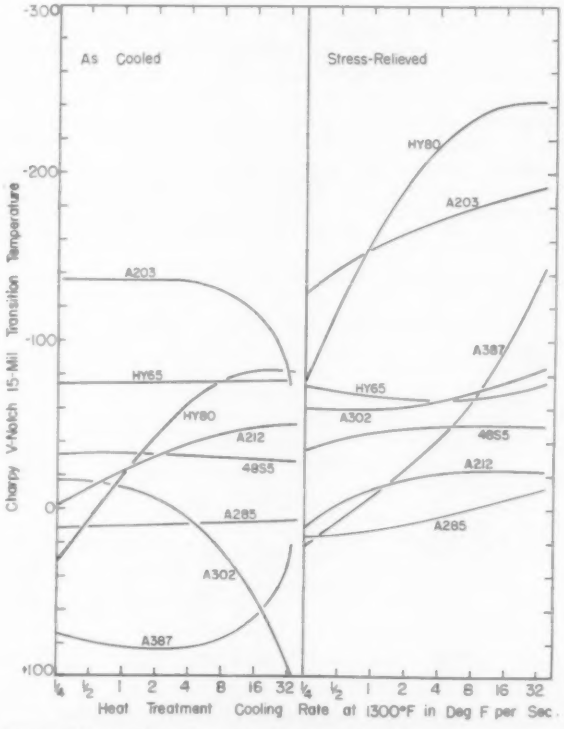


Fig. 8—Effects of cooling rate from austenitizing and of stress relief of steels on the Charpy V-notch 15 mil transition temperatures

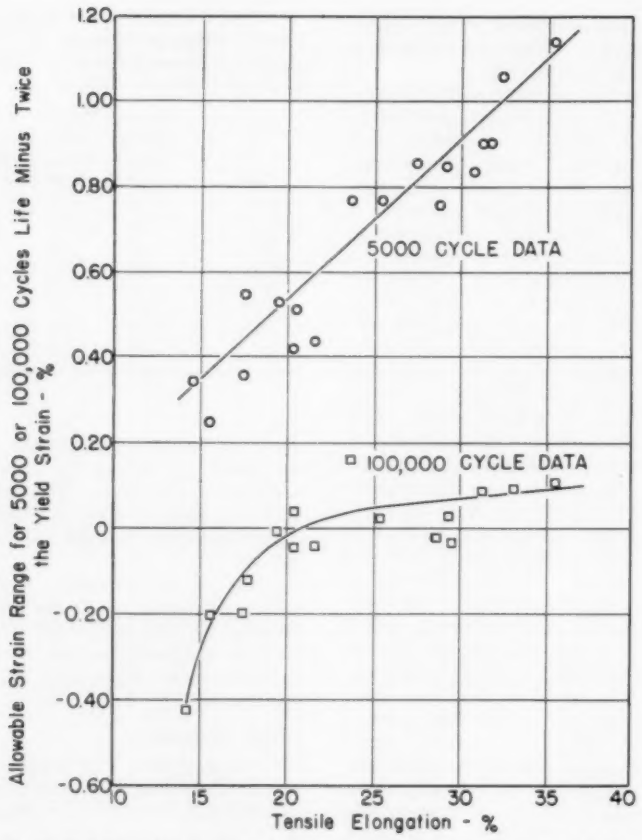


Fig. 9—Relation of the tensile ductility of steels to the allowable plastic-strain range for 5000- and for 100,000-cycle fatigue life

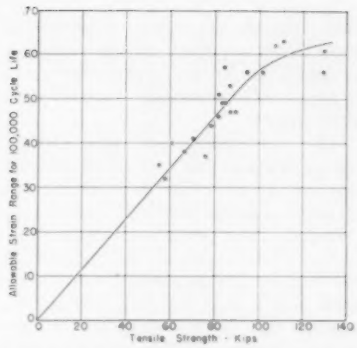


Fig. 10—Relation of the tensile strength of steels to the allowable strain range for 100,000-cycle fatigue life

program was designed to give information pertinent to pressure-vessel applications involving usually less than 1,000,000 cycles. The specimen was a flat cantilever beam with a test section $^1/_2$ by $2^1/_2$ in.

In the plastic range of cycling, the resistance of steels to failure is related most closely to tensile ductility. Figure 9 shows that, for a life of 5000 cycles, the strain range applied minus twice the yield strain can be increased directly as the percent elongation of the steel. At plastic strain levels resulting in failure in the range of 20,000 cycles, there is little to choose among the steels. The strain ranges causing failure at these low cycles constituted drastic overloading and would be avoided in service.

Strain ranges approximating yield strains are likely to be encountered in service because of the strain raisers introduced by the welded joints and other design details. It was found, from extensive analysis of the data, that no better indicator of the allowable strain at 100,000 cycle life was available than the tensile strength of the steel. In Fig. 10 the correlation of allowable strain at 100,000 cycles to tensile strength is demonstrated. Since the alloy steels have high yield-to-tensile strength ratios, a happier finding for design purposes would have been that the fatigue range increases with yield strength. T-1 steel, for example, had a yield strength three times that of the A 201, but a tensile strength only double that of A 201. The allowable strain for 100,000 cycles of T-1 is slightly less than twice that of A 201. The data of Fig. 10

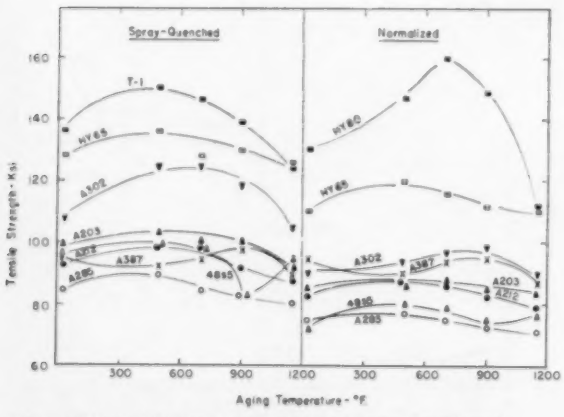


Fig. 11—Effect of 5% tensile prestrain, followed by aging at various temperatures for 1 hr, on the tensile strength of steels previously normalized or spray quenched and stress relieved

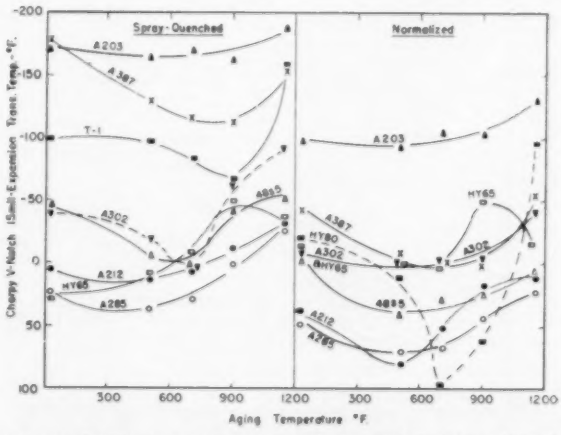


Fig. 12—Effect of 5% tensile prestrain, followed by aging at various temperatures for 1 hr, on the Charpy V-notch transition temperatures of steels previously normalized or spray quenched and stress relieved

suggest that accelerated cooling will improve fatigue resistance to about the same extent that it improves tensile strength.

Much of the advantage of a stronger steel is lost if its fatigue resistance is lowered more severely by strain-raisers, such as surface discontinuities. It was possible to compare the steels investigated not only by the cantilever-beam specimen used at Lehigh, but also from tests on hydraulically loaded plates at Illinois and model vessels at Ecole Polytechnique.[8] Table 2 summarizes the sensitivity of a number of the steels to plate surface irregularities, shallow Charpy-type notches and to sharp-cornered nozzles. There was no tendency for the higher-tensile steels to show greater sensitivity to the strain-raisers. Even with a strain-raising factor of 4, the nominal stresses required to cause failure in 100,000 cycles are one-third of the tensile strengths.

Effect of Cold Work and Strain Aging

The cold working of steel, such as in cold forming, is known to raise the yield strength markedly and the tensile strength to a lesser extent, while lowering the tensile ductility and notch ductility. Strain aging accentuates these effects, particularly lowering the notch ductility.

The effect of cold work on the high-strength steels was studied by imposing a 5% tensile prestrain on samples previously cooled to simulate spray quenched or normalized 4-in. plates, and stress relieved after cooling. Reheating the prestrained plates to a series of temperatures up to stress-relief temperature then developed the full extent of strain aging, as well as the degree of recovery at the standard temperatures of stress relief.

In Fig. 11, the changes in room-temperature tensile strength of the steels are shown as a function of reheating temperature. Maxima in the curves generally appear after reheating at about 500–700° F, where strain aging is most severe and above which the strengths drop back gradually, nearly to the levels exhibited before prestrain, by the time stress-relief temperatures are reached.

Appreciable dips in notch ductility are shown in Fig. 12 to result from strain aging at the same temperature range causing the maxima in strengths. Stress-relief temperatures restore nearly all of the original notch ductility, and may

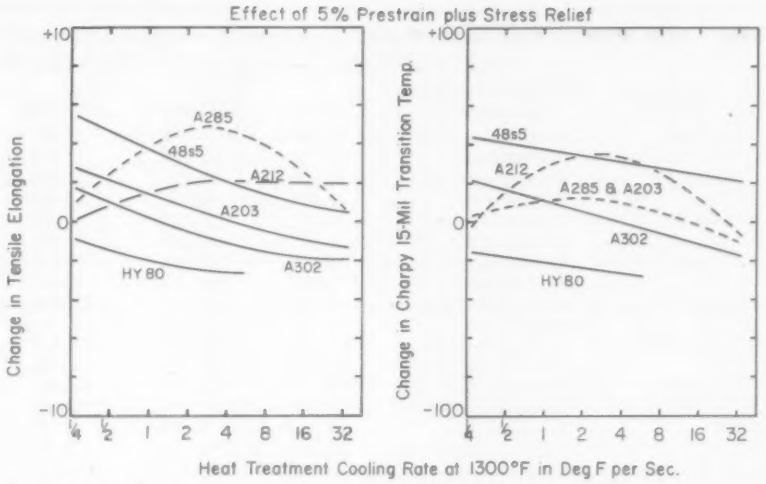


Fig. 13—Effect of accelerated cooling on the response of steels to prestrain followed by stress-relief treatment

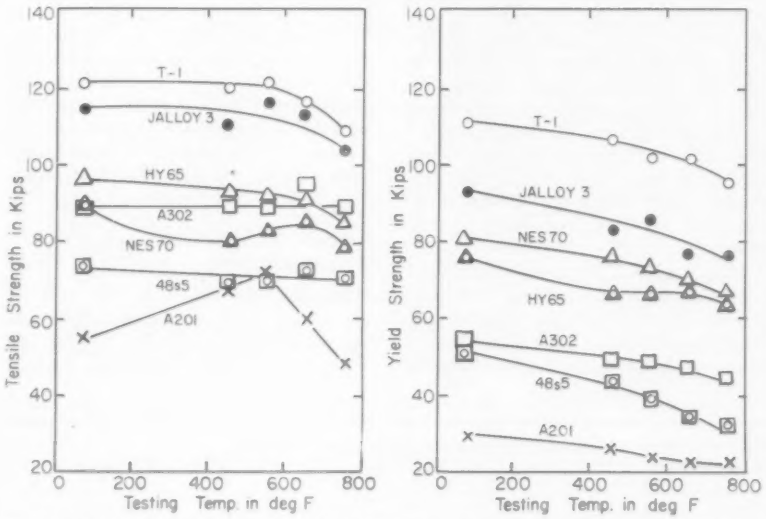


Fig. 14—Yield and tensile properties of the high-strength steels at elevated temperatures

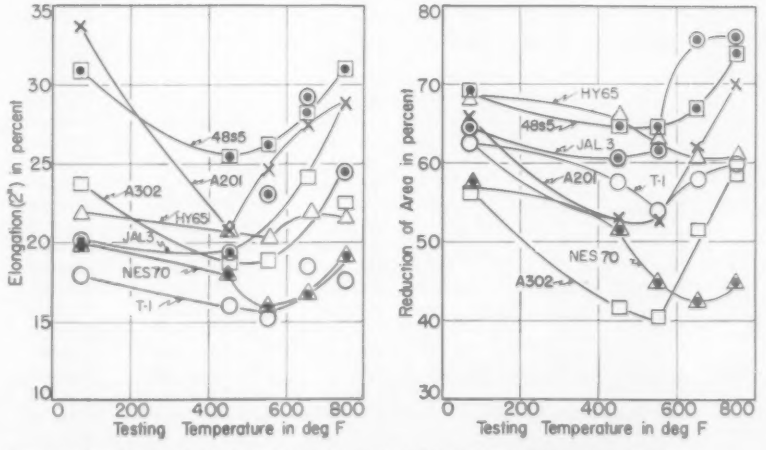


Fig. 15—Tensile ductility of the high-strength steels at elevated temperatures

Table 3—Effect of 8000-hr Exposure at 500 or 700° F on Tensile Strength and Notch Ductility of the Steels

Steel	Cooling method from austenitizing	Tensile properties			Charpy test, 15-mil transitions		
		as SR	8000 hr 500	8000 hr 700	as SR	8000 hr 500	8000 hr 700
A285	Spray quenched	74,100	75,500	76,200	−14	+4	+12
	Normalized	66,200	66,500	67,100	+16	+20	+10
A212	Spray quenched	87,800	87,400	87,300	−18	−28	−30
	Normalized	77,200	78,400	78,300	+12	−8	+2
48s5	Spray quenched	91,600	91,400	94,000	−50	−34	−36
	Normalized	76,800	72,800	74,000	−36	−24	−18
A203	Spray quenched	90,900	91,800	106,600	−180	−190	−78
	Normalized	78,500	82,800	96,400	−130	−148	−48
A302	Spray quenched	106,000	110,000	111,000	−79	−70	−78
	Normalized	85,700	84,000	85,900	−60	−68	−54
HY 65	Spray quenched	114,000	124,000	125,000	−56	−58	+6
	Normalized	104,000	106,000	118,000	−64	−50	+24
HY 80	Normalized	128,000	129,000	130,000	−76	−56	−34
A387	Spray quenched	102,000	91,500	91,100	−142	−164	−156
	Normalized	89,400	81,400	80,400	−18	−46	−46
T-1	Spray quenched	131,000	124,000	130,000	−130	−150	−92

actually improve the steels in some cases.

Only the carbon steels appeared to retain some of the strength gained by strain aging. Unfortunately, cold forming seldom produces a uniform enough plastic strain in the section to make the increases in strength useful to design. The strengths and notch ductilities of the steels relative to each other are shifted very little by prestrain if followed by thermal stress-relief treatment.

The influence of accelerated cooling prior to cold working is shown in Fig. 13. With stress relief as the final treatment, the slow-cooled steels tend, actually, to gain tensile ductility as a result of prestraining but lose notch ductility. At faster cooling rates, the change in both properties becomes negligible.

The plastic strain accompanying cold forming seldom exceeds the 5% deformation used in these tests; therefore, the results obtained should be applicable to cold-formed plates. With higher deformation, restoration of the ductility may require full heat treatment.

Effects of Elevated Temperatures

Except for the A 387 Cr-Ni steel, the steels considered here are intended for service below 650° F. Their short-time tensile properties up to 750° F are shown in Figs. 14 and 15. All the steels show a gradual drop in yield strength but no loss of tensile strength up to 650° F. The carbon steel strain aged during testing to a higher-strength level. All of the steels show a loss of ductility around 600° F because of strain aging.

The possible effects of exposures up to two years at 500 and 700° F on the strength and notch ductility of these steels were investigated for the Pressure Vessel Research Committee, and are reported in detail elsewhere. A few of the

Table 4—Metal-arc Welding-procedure Qualification Results (Performed by Chicago Bridge and Iron Co.)

Steel	Welding conditions			Qualification Position	Test, tensile-failure	Results side-bend
	Electrode	Preheat	Postheat			
45s5	E7016	None	None	Flat	77,000-plate	Passed
				Vertical	73,000-plate	Passed
				Horizontal	76,000-plate	Passed
				Overhead	76,000-plate	Passed
A302	E7016	None	1150° F	Flat	84,000- plate	Passed
				Vertical	84,000-weld	Passed
				Horizontal	84,000-plate	Passed
				Overhead	86,000-PL&W	Passed
70A	E9015	None	1100 °F	Flat	95,000-plate	Passed
				Vertical	95,000-plate	Passed
				Horizontal	96,000-plate	Passed
				Overhead	98,000-plate	Passed
70B	E10016	None	None	Flat	100,000-plate	Passed
				Vertical	105,000-plate	Passed
				Horizontal	104,000-plate	Passed
				Overhead	103,000-plate	Passed
90A	E12015	200° F	None	Flat	116,000-plate	Passed
				Vertical	117,000-plate	Failed[a]
				Horizontal	117,000-plate	Passed
				Overhead	118,000-plate	Failed[a]
90B	E12015	None	None	Flat	123,000-PL&W	Passed
				Vertical	119,000-weld	Passed
				Horizontal	124,000-PL&W	Passed
				Overhead	125,000-PL&W	Failed[a]

[a]Passed using 2.5-in. diam. ram.

Table 5—Results of Longitudinal-bead-weld Cracking Tests (Values Are Averages of Five Specimens)

Steel	Cracking, %	Equivalent carbon
A201	0	0.19
48s5HT	0	0.33
A302	58	0.42
NES 70	0	0.35
HY-65	2	0.33
Jalloy 3	76	0.55
T-1	39	0.41

Table 6—Sensitivity of the Steels to Cracking in the Lehigh Restraint Test (Expressed as Width of Specimen Required to Cause Cracking)

Steel	Qualified electrode	Cracking level with qualified electrode, in.	Cracking level with E9015 electrode, in.
A201	E7016	>8	>8
48s5	E7016	>8	3½
A302	E7016	6½	4½
NES 70	E9015	5	5
HY-65	E10015	3½	5½
Jalloy 3	E12015	6	3
T-1	E12015	>8	4½

important data are summarized in Table 3 and Fig. 16.

Table 3 shows that the tensile properties are generally not altered seriously by long exposure at these elevated temperatures. In Fig. 16 it can be noticed that several of the steels are embrittled at 700° F but not at 500° F. Evidence is available to indicate that temper embrittlement is occurring during the long sojourn at 700° F. At temperatures between 850 and 1050° F, these same steels were observed to show much more rapid temper embrittlement, but this range is outside the useful service temperatures. The gains in notch ductility obtained by accelerated cooling instead of normalizing are retained after elevated-temperature aging.

Weldability Characteristics

The weldability of steel is not an inverse property of tensile strength, but welding of the stronger steels does require more precautions. Bunk[9] demonstrated that the same steels under study here could readily be qualified under standard weld-qualification tests. Table 4 summarizes his results. Some additional laboratory weldability tests were conducted at Lehigh University on the 1-in. plates. These included underbead-cracking tests, restraint-cracking tests and Kinzel tests.

Standard longitudinal-bead-weld cracking tests were conducted in sets of five. In Table 5, the percent cracking and the calculated equivalent carbons are shown. Only those steels with equivalent carbons above 0.40% showed significant cracking. Control of the hydrogen during welding is usually adequate to avert cracking in steels up to 0.50% equivalent carbon. Above 0.50% preheating may also be required.

The Lehigh restraint specimen was used to determine the cracking tendency of weld metal deposited with qualified electrodes for each of the steels. Parallel tests were conducted with E9015 electrodes to reveal the influence of base-metal dilution on cracking sensitivity. The results of the tests are given in Table 6. The carbon and/or alloys contributed to the weld metal cause considerable lowering of the resistance to cracking. Under high restraint, preheating may be necessary to avoid cracking. With one exception, the qualified electrode for the steel performed better than the arbitrarily applied E9015.

Kinzel tests were carried out on a series of specimens unwelded,

Table 7—Results of Kinzel Tests on the As-received Steels (Transition Temperatures in ° F. at 1% Lateral Contraction)

Steel	Electrode	As-received	As-welded	Welded at 300° F	Welded and postheated	
					Single	Quadruple
A201	E7016	−120	−30	− 30	−30	− 20
48s5	E7016	−175	−10	− 20	+30	− 20
A302	E7016	− 80	+20	+ 30	−95	−155
NES 70	E9015	−120	+95	+ 5	−50	− 50
HY 65	E10015	−210	−50	− 70	0	− 5
Jalloy	E12015	−180	−20	− 80	−65	− 55
T-1	E12015	−225	−80	−105	−90	−120

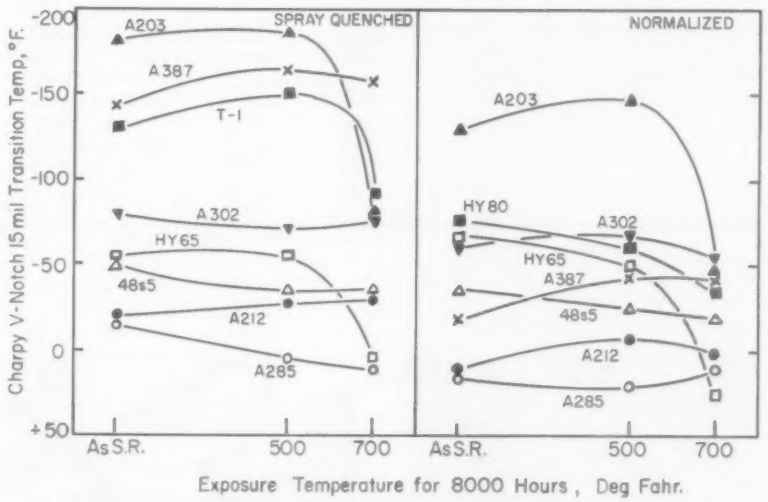


Fig. 16—Effect of 8000 hr exposure at 500 or 700° F on steels previously normalized or spray quenched and stress relieved

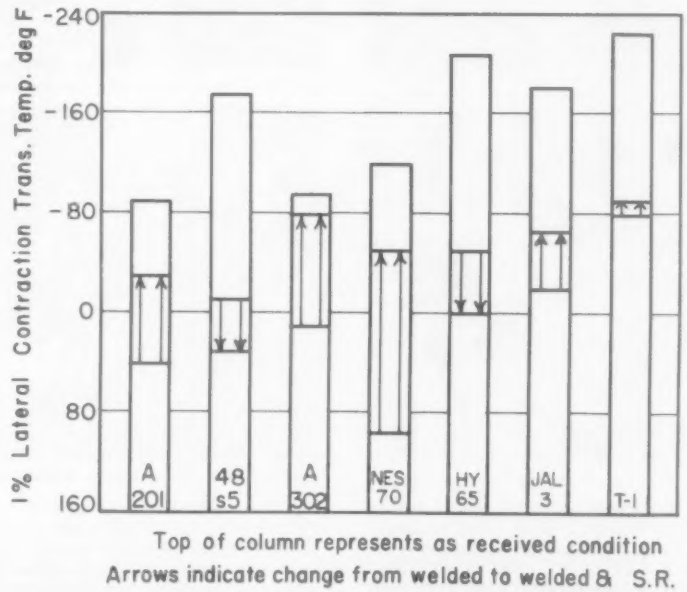


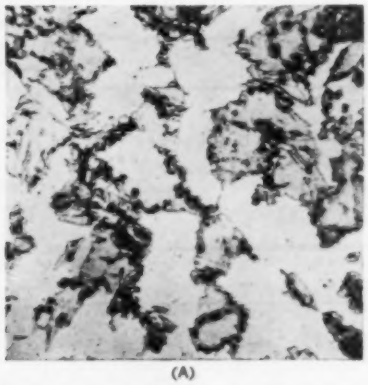
Fig. 17—Effect of welding and of stress relief on the notch ductility of the high strength steels as measured by the Kinzel test

Table 8—Effect of Simulated Weld Thermal Cycles on Normalized and Spray-quenched Steels

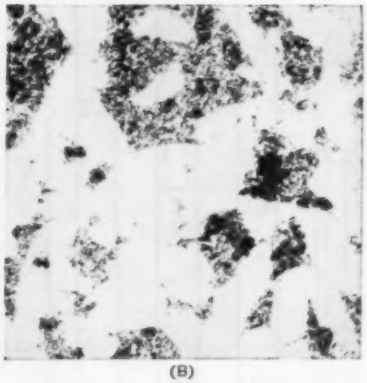
Steel and condition	Simulated maximum temperature, °F	Weld-cycle cooling rate, °F/sec	Charpy trans. temp, °F 15 ft-lb	15 mil
A302 Oil quench and SR 1150° F	before cycling		− 88	− 83
	2400	10	+ 20	+ 4
	2400	40	− 38	− 50
	2400	100	−150	− 96
	1400	10	−110	−116
	1400	40	−155	−148
	1400	100	−145	−145
Foil cooled + SR 1150° F	Before cycling		− 58	− 67
	2400	10	+ 37	+ 22
	2400	40	− 64	− 48
	2400	100	−142	− 44
	1400	10	− 72	− 90
	1400	40	−124	−116
	1400	100	−134	−140
A212 Oil quench and SR 1150° F	Before cycling		+ 31	+ 22
	2400	10	+ 85	+ 52
	2400	40	+110	+100
	2400	100	+126	+130
	1400	10	+ 2	− 10
	1400	40	+ 15	+ 5
	1400	100	+ 6	− 8

welded at room temperature, welded with 300° F preheat and welded at room temperature and stress relieved. Table 7 and Fig. 17 contain a comparison of the steels. For the most part, the higher-strength steels retain their advantage in notch toughness after welding. Additional 1-in. thick Kinzel tests machined from 4-in. plates showed somewhat greater sensitivity to welding than 1-in. rolled plates, both in the carbon and alloy plates.

The question was raised during these investigations as to the relative response to welding thermal cycles of steels treated by accelerated cooling rather than air cooling. Some preliminary tests have been completed on the A212 and A302 steels. Each steel was cooled from austenitizing at 35- or at 0.25° F per second, followed by stress relieving. Charpy bars were cut from each test plate and these were resistance heated to either 2400-



(A)



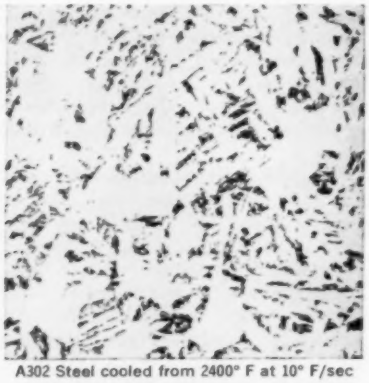
(B)

Fig. 18.—Microstructures formed in A212 steel by heating to 1400° F and cooling at 100° F per second. Figure 18A shows the as-cooled structure, while Fig. 18B shows the stress-relieved structure. Nital etch. X 500. (Reduced by 25% upon reproduction)

A212 Steel cooled at 2400° F at 10° F/sec

A212 Steel cooled at 2400° F at 100° F/sec

Fig. 19A—Microstructures formed in A212 steel by heating to 2400° F and cooling at 10 or 100° F per second, followed in each case by stress relieving. Nital etch. X 500. (Reduced by 25% upon reproduction)



A302 Steel cooled from 2400° F at 10° F/sec

A302 Steel cooled from 2400° F at 100° F/sec

Fig. 19B—Microstructures formed in A302 steel by heating to 2400° F and cooling at 10 or 100° F per second, followed in each case by stress relieving. Nital etch. X 500. (Reduced by 25% upon reproduction)

or 1400° F in 7 sec, and then cooled, 10-, 40-, or 100° F per second to simulate welding cycles. All bars were then thermally stress relieved before testing.

The experimental data are presented in Table 8. Heating to 1400° F produced improvement in both steels regardless of pretreatment or of cooling rate; but this result was contingent on the thermal stress-relief treatment which followed, a procedure normal to pressure-vessel fabrication. The 1400° F cycle, coupled with fast cooling, has been shown to be strongly embrittling if postheating is omitted. Figure 18A shows the notch-brittle martensite and ferrite mixture which, when stress relieved, is spheroidized and toughened, as seen in Fig. 18B.

The treatments at 2400° F produced effects which were variant with steel composition, but wholly independent of the prior microstructure. The A212 carbon steel was more embrittled by fast cooling than by slow. The A302 alloy steel was embrittled by slow cooling, but not by fast. The microstructures of Fig. 19 help to explain these differences. The carbon steel showed coarse grains with harder mixtures of pearlite and ferrite resulting from faster cooling, which stress relief did not alter greatly. In contrast, the alloy steel transformed to ferrite and pearlite when slowly cooled, but formed martensite if cooled rapidly. After stress relieving, the martensite was naturally greatly toughened, but the slowly cooled structure retained much of its notch sensitivity.

These preliminary tests show that the properties of the heat-affected zone are much more dependent on the welding conditions than on the prior heat treatment. In alloy steels, controlled heat input is important to the avoidance of cracks and the minimizing of embrittlement in the welded joint. Both excessively low and excessively high heat inputs can be damaging to the base metal.

Summary

How much can be decided about the applicability of higher-strength steels to welded structures from the results reviewed here? At least this much can be concluded: the laboratory tests, for what they are worth, have furnished favorable evidence of the suitability of these steels for weldments designed to higher stresses.

First, considerable gains in tensile strength can be obtained by the use of low-alloy compositions, particularly in heavier sections. Second, the increased strength is not obtained at the sacrifice of notch ductility, but indeed with the possibility of concomitant increase in toughness. Third, fatigue resistance increases roughly as the tensile strength and does not appear to be a limiting factor in the use of the steels.

An important advantage accompanying the application of higher-strength steels that is not always taken into consideration is the fact that reduced sections are possible because of higher-design stresses. The fact that thinner sections are involved in the fabrication compensates to a great extent for the forming and welding problems that may be encountered in alloy steels.

Accelerated cooling can be used to raise the strength and notch ductility of these steels, but the response of the steel depends on its hardenability. The alloy content is more critical to the properties of the steel than the range of cooling rates that can be imposed on steels of relatively heavy sections. A good deal is yet to be learned about the applicability of accelerated cooling. Tests are presently in progress to determine whether improved surface properties will be effective in raising the service usefulness of sections above 1-in. thickness.

Among the remaining problems is the development of electrode materials and welding techniques which will produce weld metal that fully matches the potential properties of the base materials. The higher the specification of design stresses, the more difficult this objective becomes.

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Solicitation of Current Welding Research Problems

About once every two years the Welding Research Council circularizes subscribers and research workers affiliated with the Council to determine if they have any research problems which they believe should be undertaken and which do not appear to be receiving due consideration. This list will then be used by the University Research Committee and Project Committees of the Council in compiling a list of problems suitable primarily for University study.

It would be greatly appreciated if all readers of this notice would submit such problems in welding and closely allied fields because this information will be extremely useful to universities, industry and government agencies in identifying the most urgent problems in these areas. A list will then be compiled and published in the Welding Research Supplement later in the year.

Please submit suggested problems to the Welding Research Council, 29 W. 39th St., New York 18, N. Y.

Resistance Welding Electronic Component Leads to Nickel-Clad Copper Wire

Laboratory investigation leads to recommendations on best welding setup and on optimum welding schedules for this type of work

By W. L. HUGHES

Introduction

Background

All-welded electronic circuitry has been considered for several years. Due to the difficulty in welding tinned copper, brass, copper-clad nickel-iron wire,* and gold-plated nickel-iron-cobalt† wire electronic component leads, the concept of an all-welded, rather than soldered circuit, has never progressed much beyond the talking stage. Recent developments in high-temperature circuit techniques have made available to the designer two new conductors specifically designed for interconnecting wires and component lead materials for operation at 500 to 700° C. These materials are nickel-clad copper wire‡ and stainless-steel-clad copper wire.§ The conductivity of the wires is approximately 70% that of a solid copper wire. The cladding wall is about $7^1/_2$% of the diameter in thickness, i.e., a 0.10-in. diam wire will have a cladding wall about 7 to 8 mills thick. The wires are currently commercially available in diameters from 0.003 to 0.3 in. fully cold worked or annealed to any desired condition up to dead soft. Both of these materials have been used for experimental high-temperature circuits with success. Two joining methods were used: gas tungsten-arc welding and resistance welding. Welding is necessary for high-temperature circuitry because soft solders melt at the operating temperatures of such circuits. Brazing may be useful when and if a brazing filler metal is developed that resists oxidation after prolonged exposure in air at 500° C. Past attempts at resistance welding so-called common low-temperature component lead materials resulted in only marginal success. Fusion welding using a capacitor arc discharge or inert-gas tungsten-arc technique, while successful, usually has been abandoned in favor of a solder technique due to high manufacturing cost and joint-embrittlement problems of these processes. Resistance welding offers greater possibilities for automation due to the relative ease with which equipment may be designed and operated. It is more convenient to use, less hazardous, requires little or no operator skill, is not as subject to operator discretion, and need not be shielded except by clear safety glass since there is no intense light source.

From a resistance-welding standpoint, it is not difficult to join copper to nickel. When nickel-clad copper wire became available, a definite breakthrough was made in overcoming a difficult resistance-welding problem that had up to that time prevented the adoption of the process to electronic-circuit work. Nickel-clad copper wire can easily be resistance cross-wire welded to itself and, in addition, may be welded to the tinned copper wire used on the majority of resistors and capacitors. Further investigation led to the discovery that nickel-clad copper wire may be brazed to the copper-clad nickel-iron lead wires in common use on miniature glass diodes and transistors. The copper plate on the copper-clad nickel-iron wire becomes the brazing filler metal. Tinned or bare, nickel-iron-cobalt wire, used on transistors by some manufacturers, cannot easily be joined to nickel-clad copper wire. However, JAN transistors having gold-plated nickel-iron cobalt lead wires may be brazed to nickel-clad copper wire by a resistance welding process. The gold plate becomes the brazing filler metal. Tinned brass wire used on a few types of mica capacitors may also be brazed to the nickel-clad copper wire. In this case, the brass becomes its own filler metal. These processes are not critical. The tinning normally present on component leads does not interfere with the welding or brazing operation. The wires which will merely braze and not weld to the nickel-clad copper wire still have excellent mechanical characteristics after processing.

The brazed joints will not fail from the application of heat until the melting point of the base metal is reached which is far in excess of solder melting points. Normal tensile tests of the brazed joints indicate values which have 80 to 90% the strength of the base wire. The time required is short, normally 3 milliseconds welding time per joint. Glass-encased germanium diodes suffer no detectable ill effects when joined to nickel-clad copper wire $^1/_{16}$ in. from the glass case.

What has been said of joints made with nickel-clad copper wire appears to be generally true if stainless-steel-clad copper wire is used. However, a complete evaluation using stainless-steel-clad copper wire has not been made. The stainless-steel-clad

* Known commercially as "Dumet."

† Known commercially as "Kovar."

‡ Known commercially as "Kulgrid."

§ Known commercially as "Oxalloy 28."

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copper wire costs four times as much as the nickel-clad copper wire. Its use as a foundation on which electronic circuits may be constructed probably could not be justified. For this reason, its application will, no doubt, be limited to very high-temperature work.

Up to the advent of nickel-clad copper wire, various forms of copper weld wire were used when it was desirable to join low-temperature electronic components by a resistance welding process. The fact that this material never gained wide usage may be due to the fact that the operation is critical and subject to wide variation of end result if it is not controlled closely. If it is permitted to define an arbitrary scale from 1 to 10, listing the order of estimated difficulties one encounters when cross-wire welding, with nickel to nickel as No. 1 (an easy noncritical task) and No. 10 copper to copper joint (a difficult critical task) as comparison points, these joints may be characterized as follows:

Combination	Number
Nickel-clad copper wire to nickel-clad copper wire	3
Nickel-clad copper wire to copper	3
Nickel-clad copper wire to copper-clad nickel-iron wire	4
Nickel-clad copper wire to gold-plated nickel-iron-cobalt wire	3
Nickel-clad copper wire to brass	3
Weld wire to weld wire	3
Weld wire to copper	7
Weld wire to copper-clad nickel-iron wire	4
Weld wire to gold-plated nickel-iron-cobalt wire	4
Weld wire to brass	5

Up to this point no mention of equipment or technique has been made. We have recently completed a rather extensive investigation into these subjects in so far as they affect the proposed production welding of electronic circuits using a resistance-welding technique to join nickel-clad copper wire to tinned copper, brass, copper-clad nickel-iron wire or gold-plated nickel-iron-cobalt wires.

The following power sources were investigated (see Fig. 1):

60-cycle ac (synchronous)
60-cycle programmed heat (synchronous)
Capacitor discharge

The following types of welding heads were also checked for performance:

Position fired

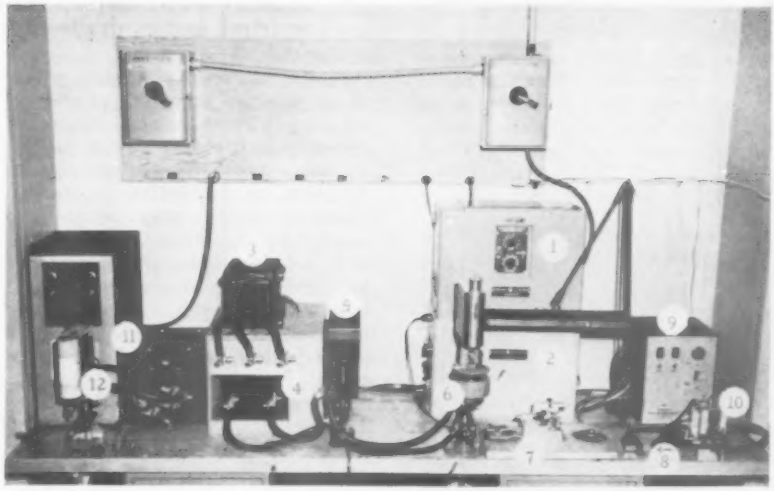


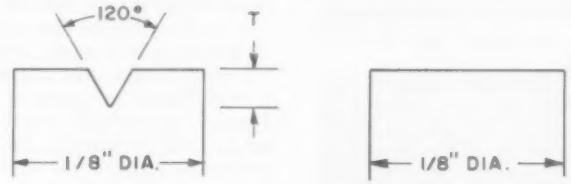
Fig. 1—General view of laboratory bench-welding area

Equipment identity as follows: (1) single-phase a-c synchronous control; (2) up-down slope control for (1); (3) 1-2½ kva and, (4) 5-kva transformer for (1); (9) 18-w sec capacitor discharge power supply; (11) 225-w sec capacitor discharge power supply. Any supply may be switched in and/or connected to: (5) 2- to 30-lb position-fired head; (6) 12- to 45-lb magnetic follow-up head; (12) 5- to 50-lb force-fired head; (10) 2- to 15-lb force-fired head; (7) 1- to 10-lb butt-weld head; (8) 1- to 5-lb force-fired tweezer weld plier.

Table 1—Recommended Resistance-welding Schedules for Joining Electronic Component Leads to Nickel-clad Copper Wire

Nickel-clad copper wire to tinned copper, brass, copper-clad nickel-iron wire and gold-plated nickel-iron-cobalt wire.

Equipment: Capacitor discharge, force-fired bench head 1/8-in. diam. AWS Gr. A, Class 2 electrodes, contoured as shown in accompanying sketch, 10 lb force.



A-B-C D

	Electrode	T, in.
Wire in groove where indicated	A	0.010
	B	0.015
	C	0.020

Wire adjacent upper electrode diameter (in.)-material	Upper electrode	Lower electrode	Energy, watt-sec
With 0.020-in. diam nickel-clad copper wire in lower electrode			
0.020 nickel-clad copper wire	A	A	31
0.020 tinned copper	D	A	35
0.017 gold-plated nickel-iron-cobalt wire	A	D	12.5
0.020 copper-clad nickel-iron wire	A	D	15
With 0.024-in. diam nickel-clad copper wire in lower electrode			
0.024 nickel-clad copper wire	B	B	35
0.020 tinned copper	D	B	35
0.017 gold-plated nickel-iron-cobalt wire	A	D	12.5
0.020 copper-clad nickel-iron wire	A	D	15
With 0.030-in. diam nickel-clad copper wire in lower electrode			
0.030 nickel-clad copper wire	C	C	80
0.030 tinned copper	D	C	90
0.020 tinned copper	D	C	50
0.032 tinned brass	C	C	45
0.020 copper-clad nickel-iron wire	A	D	15
0.017 gold-plated nickel-iron-cobalt wire	A	D	17

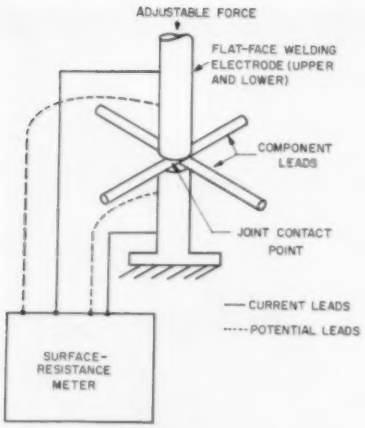


Fig. 2—Cross-wire resistance check (same configuration as welding setup)

Magnetic follow-up
Force fired

The following electrode materials were checked:

AWS GR A Class 1
AWS GR A Class 2
AWS GR A Class 3
AWS GR A Class 13
Molybdenum

Conclusions

The best welding setup for this type of work is capacitor discharge and a force-fired head equipped with $^1/_8$-in. diam GR A Class 2 electrodes. Optimum schedules for the above equipment are included in Table 1.

Discussion

Surface Resistance

A resistance-welding schedule specifies three primary parameters. These are related to a fundamental expression, $H = I^2RTK$, where H = heat in watt seconds when I = current in amperes, R = resistance in ohms and T = time in seconds. K is a dimensionless mathematical constant usually less than unity that is dependent on the electrical and thermal efficiency of the system.

Experience in cross-wire welding of copper wires has demonstrated the need for precise control over all factors affecting the variables in the above expression. For this reason, the equipment evaluated for this project was chosen from types offering adjustable, yet precise, reproducible control over current, time and, in so far as possible, resistance. K is primarily dependent on electrode alloy, size, face contour, length and material to be welded. No academic attempt will be made to determine K. However, the factors known to effect its value were closely watched and controlled to keep its value constant.

Precise control over current offers no particular problem, providing the closed circuit through which the current will pass has approximately the same impedance for each weld. All electrical connections in such a circuit, with the exception of that formed by the joint to be welded and the electrodes, are permanent and assumed to be constant. Factors affecting the reactive component of the circuit impedance can easily be held constant for a given setup, i.e., supply lead spacing, distance between electrode arms, fixtures, throat depth, etc. Even though these items are relatively easy to hold constant, they must be considered because pronounced changes in current delivered can be affected by changing from, say, a no-fixture condition to a setup where a magnetic fixture is held close to or surrounding the electrodes. During this investigation, reactive components were held essentially constant for each setup.

The bulk resistance of the materials to be welded is relatively constant and dependent on the metals or alloys involved. The contact resistance between wires to be welded and the welding-machine electrodes must now be considered. The welding controls evaluated were from types which provide exactly the same preset current at the welding electrodes for each weld. As mentioned earlier, the resistance in the circuit exclusive of the electrode-joint-electrode portion is held predictably constant. Further discussion of the reactance will not be made. It is assumed constant, as necessary precautions to keep it thus have been made.

To keep the power input constant, it is necessary that the joint-electrode contact resistance be constant. (Resistance-welding power supplies act like constant-current generators; if resistance rises slightly, voltage also rises to keep current constant, resulting in a higher power input.) Now, consider the joint-contact resistance.

The setup in Fig. 2, as are all similar configurations involving two members, at least one of which is a round wire, provides a projection-welding situation. The contact between the two wires is, ideally, a single point while that between the wires and electrode is a line contact of much greater area. Normally, the highest contact resistance will occur at the joint where a weld is desired. Electronic component leads are usually coated by a "tinning" method with a tin-lead soft-solder type alloy. This material is usually covered with a film of dirt, wax and oxides. A sufficient force must be exerted on the joint to break through this film, if a reasonably constant resistance is to be established. Cleaning by mechanical or chemical methods, while esthetically ideal, would involve costs and additional steps which do not appear desirable if a satisfactory constant resistance can be reached without these processes.

To determine the contact resistance under various electrode forces, the setup in Fig. 2 was adopted. This allows a measurement of the joint resistance under various static loads. The total resistance includes that of electrodes, wires and the three contact points. By checking

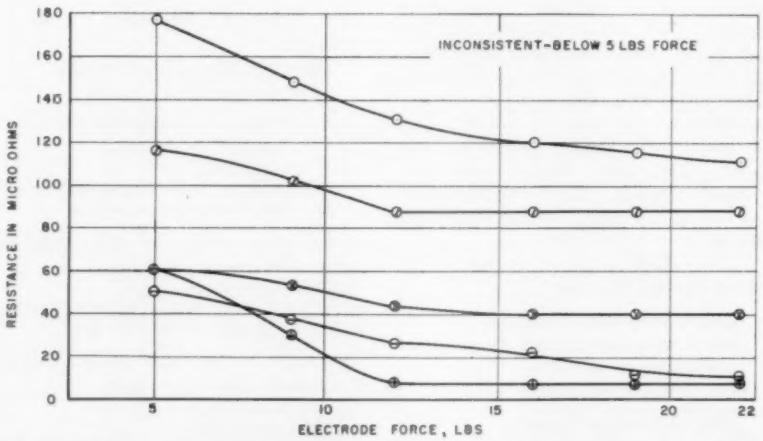


Fig. 3—Joint resistance vs. electrode force for 0.020-in. OD nickel-clad copper to ⊙ 0.020-in. OD nickel-clad copper, ⊕ 0.020-in. OD tinned copper, ⊘ 0.017-in. OD gold-plated nickel iron-cobalt, ⊗ 0.017-in. OD tinned copper-clad nickel iron, ⊖ 0.020-in. OD tinned brass

Fig. 4—Internal (microsection) of 90-deg cross-wire joint between 0.030-in. diam nickel-clad copper wire and 0.032-in. diam tinned copper made on 60-cycle a-c. equipment

Note formation of Monel in nickel-clad copper wire just above joint interface, penetration of grain growth crystal structure into copper wire (light-texture zone near joint interface). Direct tensile value of this joint averages 20 lb. The interface zone is typical of a braze between copper and nickel. X 75. (Reduced by 33% upon reproduction)

Fig. 5—Internal (microsection) of 90-deg cross-wire weld between 0.030-in. diam nickel-clad copper wire and 0.032-in. diam tinned copper made on capacitor-discharge equipment

Note formation of Monel between nickel outer skin of nickel-clad copper wire and tinned copper wire indicating part of copper went into solution with the nickel fulfilling requirements of a true weld. Heat-affected area in copper wire is almost nonexistent, uniform original grain structure still present. Direct-tensile value of joint averages 20 lb. X 75. (Reduced 33% upon reproduction)

the resistance of one wire yielding two line contacts, plus other tare values, and subtracting from the reading of the two-wire joint, the approximate resistance of the point contact between wires alone may be calculated. This procedure was followed for the following wire combinations:

(1) 0.020-in. OD nickel-clad copper to itself, to 0.020-in. OD tinned copper and brass, to 0.017-in. OD tinned gold-plated nickel-iron-cobalt, and to 0.017-in. OD copper-clad nickel-iron; (2) 0.030-in. OD nickel-clad copper to itself, to 0.030-in. OD copper and brass, to 0.017-in. OD tinned gold-plated nickel-iron-cobalt and to 0.017-in. OD copper-clad nickel-iron.

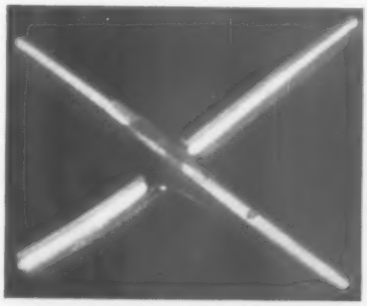
The results of these tests are shown on the graphs in Fig. 3.

Power Supply, General Requirements

Three different power-supply arrangements in common use at the present time were investigated. Each of these types is capable of consistently and accurately metering out a preset current of precise duration and magnitude. There are other types of power supplies which are less expensive, less accurate, but unsuitable for the objectives of this program; i.e., consistently welding copper to nickel and iron-bearing alloys in wire form. The three power supplies investigated are as follows: synchronous alternating current, synchronous programmed-heat alternating current and voltage-regulated capacitor discharge.

When a wrought material such as an electrolytic tough-pitch copper wire is welded, a cast microstructure results. The cast microstructure is brittle compared to the wrought microstructure. No detectable cast microstructures were produced in the joints during this investigation. However, there is grain growth in the joint area. The cross-sectional area of each wire in a 90-deg cross-wire weld is reduced considerably. Cross-sectional area reduction weakens the wire adjacent to the joint. If the wires are subsequently bent several times with the joint as focal point, fracture at this point will usually occur. This failure, commonly called brittle failure, is not the result of a metallurgical change in the copper caused by welding. The grain growth is so slight that it is not considered to have detectable effect on the strength of the wire. The grain-growth pattern does indicate the efficiency of the joining process and clearly shows the area of maximum heat.

To make a successful 90-deg cross-wire weld or braze, it is only necessary to bring the joint interface up to welding and/or brazing temperature. Excessive heat will usually cause a greater reduction in cross section and a joint incapable of withstanding deformation from bending moments without premature failure.



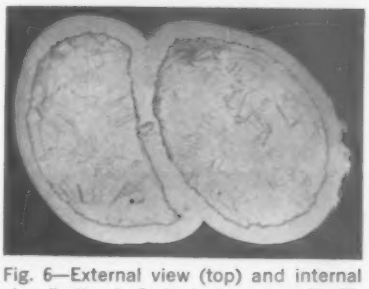


Fig. 6—External view (top) and internal view (bottom) of a typical good-quality 90-deg cross-wire weld. Actual material: 0.030-in. diam nickel-clad copper wire. X75. (Reduced by 50% upon reproduction)

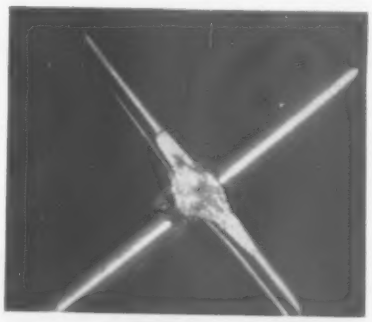


Fig. 7—External view (top) and internal view (bottom) of a typical poor-quality 90-deg cross-wire weld. Actual material: 0.030-in. diam nickel-clad copper wire welded with excessive heat on flat electrodes, note expulsion. X75. (Reduced by 50% upon reproduction)

Because of the high electrical conductivity of copper, joints having a grain-growth zone only a few thousandths of an inch thick are nearly impossible to produce, unless a suitable procedure is employed to put the heat where it is needed.

It is believed that the electrical resistance of nickel, plus its affinity for copper, account for the relative ease with which nickel-clad wires may be joined to bare or tinned copper and high-copper-alloy conductors such as brass and copper-clad nickel-iron wire. Nickel wets copper, or it might be said more correctly, that copper wets nickel easily.

When a high welding current is passed through a nickel-clad copper wire in contact with another copper wire, both clamped between copper welding electrodes, the point of highest temperature occurs at the nickel-copper interface. This will be the weld or braze point if the current is of sufficient magnitude.

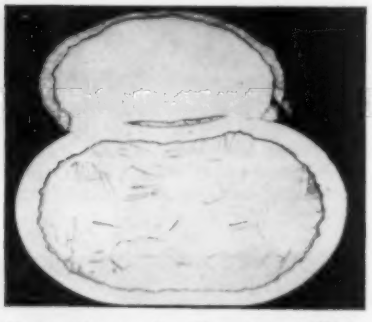


Fig. 8—Microsection through a 0.020-in. diam copper-clad nickel-iron wire and 0.030-in. diam nickel-clad copper-wire brazed joint. Copper skin on copper-clad nickel-iron wire serves as brazing filler metal. X75. (Reduced by 40% upon reproduction)

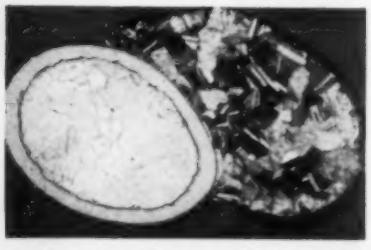


Fig. 9—Internal (microsection) of typical 90-deg cross-wire joint between 0.030-in. diam nickel-clad copper wire and 0.032-in. diam tinned-brass wire

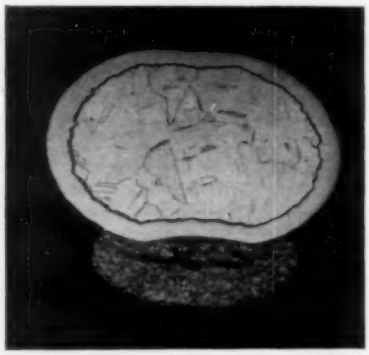
There is no evidence of fusion in this joint. Correct characterization would be that of a typical brazed joint. All tin has been expelled from 60% of the joint area. This joint, while not actually welded, will withstand temperatures up to the melting point of the brass wire prior to failure. X 75. (Reduced by 60% upon reproduction)

Program Timer

Some time ago an up-slope–down-slope 60-cycle a-c power supply was introduced. The up-slope current heats a high-conductivity material raising the resistance; the full-weld current welds the materials; the down-slope current slowly cools and anneals the joint such as in a copper-to-copper cross-wire weld. This type of power supply is capable of producing good welds in high-conductivity materials. The down-slope anneal period is effective. The degree of deformation of wires adjacent to the joint was higher than that produced for equivalent strength joints produced on capacitor-discharge equipment.

Alternating Current, 60 Cycle

A synchronous a-c supply can also produce good joints between the materials evaluated. However, greater deformation adjacent to the joint seems to be unavoidable with the necessarily longer welding-time cycles needed with straight a-c supplies. This reduces slightly the number of bends the wires can withstand after welding.



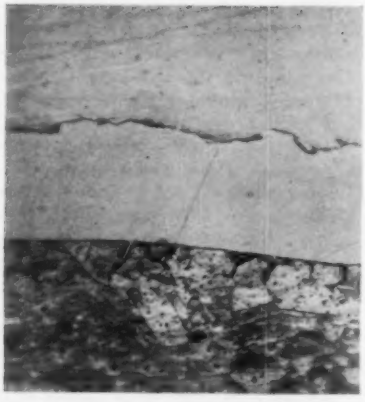


Fig. 10—Overall view (top, at X75) and joint boundary (lower, at X250) of gold braze between 0.017-in. diam gold-plated nickel-iron-cobalt alloy wire and 0.030-in. diam. nickel-clad copper wire. Note gold plate, light skin on nickel-iron-cobalt alloy wire in upper photo and penetration of gold along grain boundaries in lower photo. (Reduced 40% upon reproduction)

Capacitor Discharge

This equipment will provide $^1/_2$-cycle-type pulses of current of a 3- to 20-millisecond duration. Provision is also made to eliminate oscillation and transient tailing heat. Such equipment produces joints quite similar to the straight a-c equipment with the exception that it is possible to actually weld the copper wires to the nickel-clad copper wire. There are other differences of a more subtle nature in the crystalline structure of similar joints produced on 60-cycle and capacitor-discharge equipment (see Figs. 4 to 10). There is more grain growth in joints made with a-c equipment. This appears to be due to the longer weld pulse. A capacitor-discharge welding-current pulse suitable for joining the conductors evaluated is of three millisecond duration vs. the 8.3 or 16.6 ($^1/_2$–1 cycle) millisecond pulse obtainable on a-c equipment. A phase-shift heat timer on the a-c equipment permits the use of even shorter intervals of current than $^1/_2$ cycle, however. Generally poor results ensue if less than $^1/_4$ cycle is used, since the peak current is reduced. As the phase-shift heat is is adjusted to, say, 50% ($^1/_2$ of $^1/_2$ cycle or $^1/_4$ cycle) the shape of the pulse is changed so that rise time is nearly infinite. A pulse of this form generates so much heat so fast that the electrodes, more often than not, fail to follow up the instantaneous collapse of the conductors and an arc may be drawn between the electrodes. It is not possible to simulate exactly a capacitor-discharge type pulse with a 60 cycle a-c control. Even though a close approximation can be made, this condition can be met only for specific magnitudes of current which are controlled by welding-transformer taps. Tests indicate that the leading shape of the welding-current pulse is quite important. There should be a rise time of about 0.5 millisecond. Fall time should be as short as possible to minimize grain growth in the conductors. The capacitor-discharge pulse comes very close to what the tests indicate is an ideal welding pulse for this type of work.

Welding Heads

Three fundamentally different welding heads were checked for over-all performance. They are as follows: force-fired device; position-fired device; and a force-

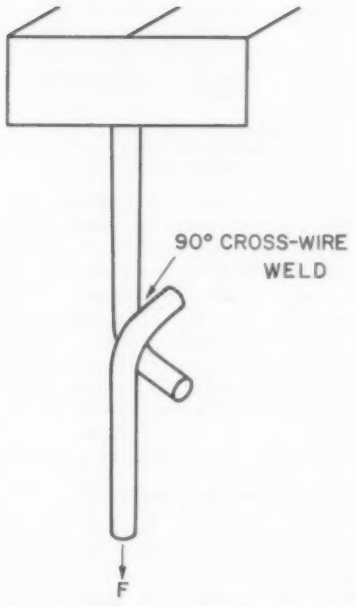


Fig. 11—Direct-tensile test of 90-deg cross-wire weld

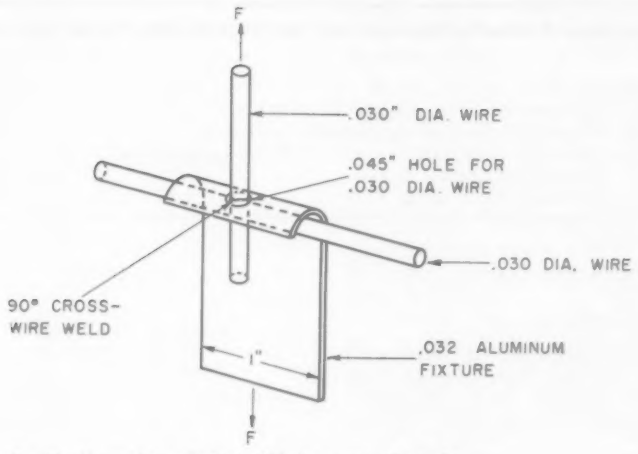


Fig. 12—Normal-tensile test of 90-deg cross-wire weld

fired magnetic follow-up device. Each head will make excellent joints when set up according to the manufacturer's instructions.

Magnetic Follow-up

A magnetic head has a fixed electromagnet surrounding the upper electrode called the stator. The welding current passes through a winding on the stator. An adjustable soft-iron armature fastened to the upper-electrode operating arm is positioned so that the magnetic field set up by the stator attracts the armature, which increases the force on the upper electrode proportional to and in synchronism with the welding current. The magnetic follow-up principal has been used to advantage in solving other welding problems. It is also well to point out that electrode wear changes the initial stator-armature gap. The magnetic force is proportional to the square of the distance between the stator and armature.

Position Fire

Position firing requires that the upper electrode be brought to a specific vertical position before the firing switch can be initiated. This is good since double firing is almost impossible. However, even slight wear in the electrode surfaces results in a change in the force developed on the joint before the weld current starts.

Force Fire

Force fire means that the welding current starts only after the upper electrode strikes the work and builds up an accurately preset force. The vertical position of the upper electrode has nothing whatever to do with firing the welding machine unless it strikes an object capable of resisting further movement with a reactive force equivalent to that which has previously been preset on the weld head.

Electrode wear cannot change the firing force within the operating stroke of the head. This does not mean that proper follow-up will occur if the electrodes wear or are set up so that the upper electrode is at the end of its vertical travel.

Electrodes

All common electrode alloys work quite well to produce crosswire welds between the materials investigated. The most favorable, from a wear and sticking standpoint, proved to be AWS Group A Class 2, a copper-chromium alloy with about 85% of the electrical conductivity of copper.

Tests were limited to electrodes with flat and grooved surfaces $^1/_8$ in. in diameter. Some improvement in cross-section shape of the welded cross-wire joint can be made by cutting a groove in the top of the electrode into which the wires are placed for welding. This increases the contact area between wire and electrode and reduces the deformation caused by higher temperatures on the single-line contact of a flat surface. The advantages of a grooved electrode should be utilized in production setups wherever possible.

Nickel-clad copper has a high skin resistance and will collapse first when welded to tinned copper or brass. To equalize the heating effect and collapse of the nickel-clad conductors, a grooved electrode may be used on the side of the joint facing these wires. While not a requirement for production of good joints, it is a suggestion that will produce a somewhat better over-all appearance.

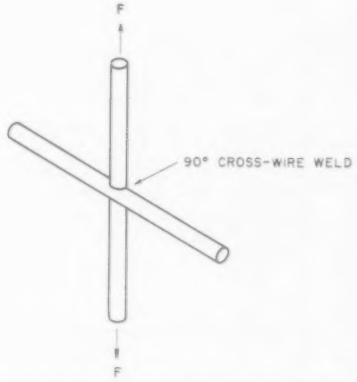


Fig. 13—Tensile test of wire on which a 90-deg cross-wire weld has been made

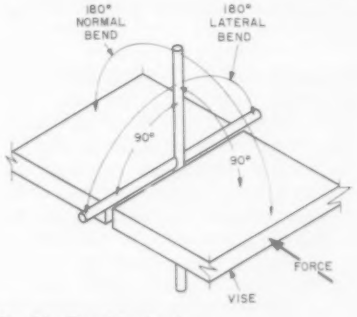


Fig. 14—Bend-test setup

Table 2—Type of Tensile Test Made on .030 "to .030" Nickel-clad Copper-wire Joint

Sketch		Avg. pull, lb
Fig. 11	Direct-tensile of 90-deg cross-wire weld joint	20
Fig. 12	Normal-tensile of 90-deg cross-wire weld joint	28.5
Fig. 13	Normal-tensile of wire on which a 90-deg cross-wire weld joint had been made	28.5
	Tensile-strength of wire	32.6

Results

Surface Resistance

Surface-resistance measurements for the various wire combinations checked indicate that consistent, reproducible values could not be obtained until 5 lb minimum electrode force was used. A plot of surface resistance vs. electrode force from 5 to 25 lb appears in Fig. 3. Resistance continues to decrease and level off as electrode force is increased; this is due to the steadily increasing surface area in contact as one wire is mashed into the other. All welding schedules were set up using an electrode force of 10 lb minimum giving a 100% safety factor on joint surface-resistance consistency.

Welding Schedules

Table 1 is almost self-explanatory. Each schedule calls for an optimum electrode contour, diameter, material and force for the wire combination in question. Energy is given in watt seconds, a convenient value for a capacitor-discharge welding-machine setup. The energy is computed as follows:

$$E = CV^2/2$$

where

E = energy in watt-seconds
C = capacitance in farads
V = charge in volts

This may be converted to a value for use on 60 cycle a-c equipment as follows:

$$E = I^2RT$$

where E = energy in watt-seconds when

I^2 = current in rms amp
R = resistance in ohms
T = time in seconds

Joint resistance at various electrode forces may be found from graphs supplied in Fig. 3. Time must be preset at one cycle, 0.0166 sec, or $^1/_2$ cycle, 0.00833 sec. Solve equation for I. This will give current magnitude in rms amperes required for a joint of equivalent tensile strength. It is not likely to produce a true weld and will be substandard in resistance to mechanical bending data supplied.

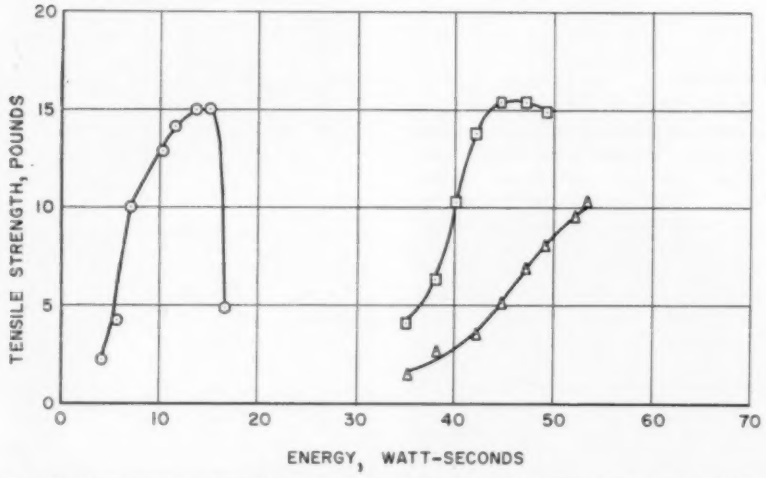


Fig. 15—Direct-tensile strength of 0.030-in. diam nickel-clad copper wire to: ⊙ 0.017-in. diam gold-plated nickel-iron-cobalt wire, △ 0.020-in. diam tinned-copper wire, ⊡ 0.030-in. diam tinned-brass wire vs. energy output of capacitor-discharge welding power supply in watt seconds. Electrode force 10 lb, contoured as shown in Table 1

Tensile Strength Vs. Energy

The graphs in Figs. 15 to 18 indicate what happens when 90-deg cross-wire joints are subjected to a direct-tensile test, probably the most severe destructive test applicable to joints of this nature. Each graph is plotted against energy in watt-seconds for ease in plotting the data. Energy was increased to the point where a burnout or complete collapse took place in each case. A direct-tensile test results in the lowest value of ultimate strength. This is caused by the torsion applied to the joint in such a test. For comparison, take the 0.030- to 0.030-in. nickel-clad copper-wire joint on which tensile tests were made in three different ways, as given in Table 2.

Test results were taken on identical welded joints. The weld operation weakens the wire reducing the

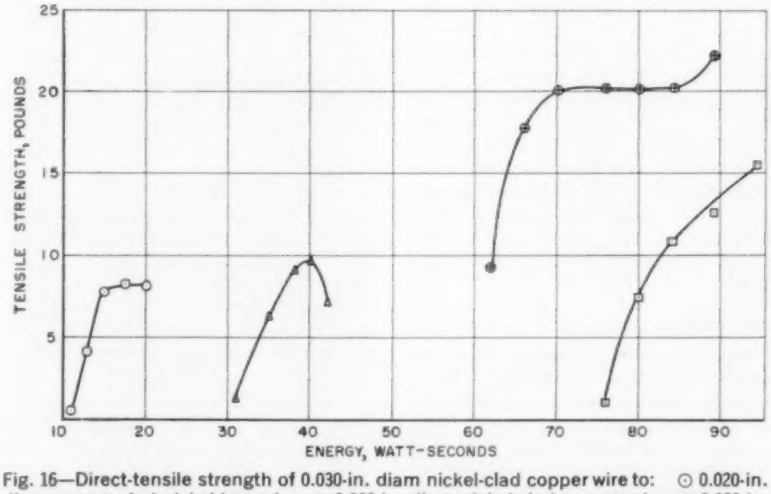


Fig. 16—Direct-tensile strength of 0.030-in. diam nickel-clad copper wire to: ⊙ 0.020-in. diam copper-clad nickel-iron wire, △ 0.020-in. diam nickel-clad copper wire, ⊡ 0.030-in. diam tinned-copper wire, ⊗ 0.030-in. diam nickel-clad copper wire vs. energy output of capacitor-discharge welding power supply in watt seconds. Electrode force 10 lb, contoured as shown in Table 1

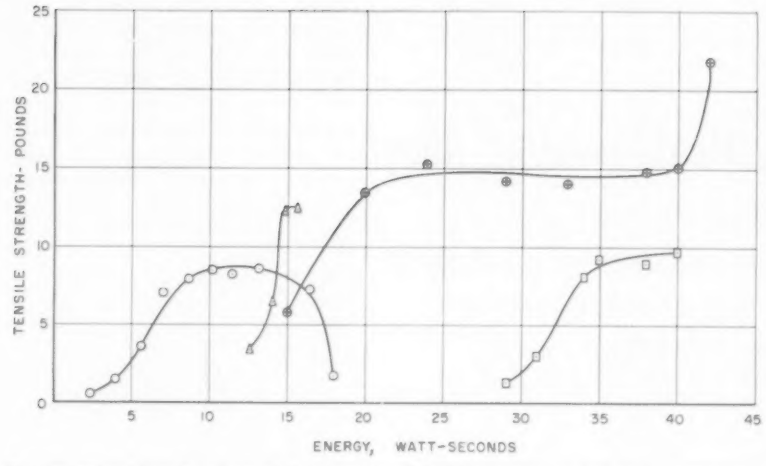


Fig. 17—Direct-tensile strength in pounds of 0.024-in. diam nickel-clad copper wire to: ⊙ 0.017-in. diam gold-plated nickel-iron-cobalt wire, △ 0.020-in. diam copper-clad nickel-iron wire, ⊡ 0.020-in. diam tinned-copper wire, ⊕ 0.024-in. diam nickel-clad copper wire vs. energy output of capacitor-discharge welding power supply in watt seconds. Electrode force 10 lb, contoured as shown in Table 1

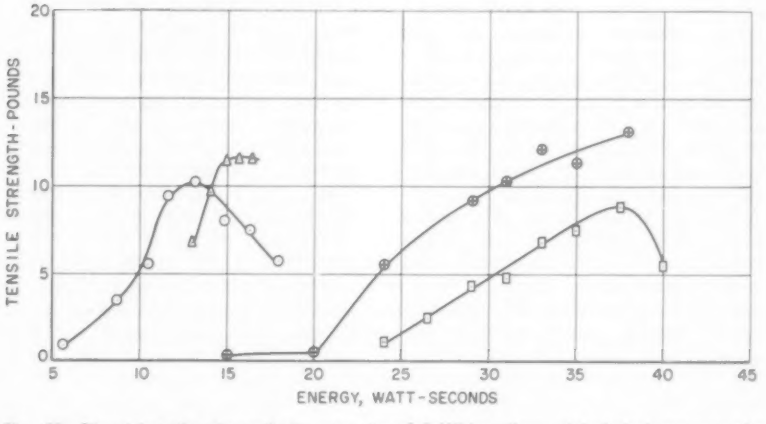


Fig. 18—Direct-tensile strength in pounds of 0.020-in. diam nickel-clad copper wire to: ⊙ 0.017-in. diam gold-plated nickel-iron-cobalt wire, △ 0.020-in. copper-clad nickel-iron wire, ⊡ 0.020-in. tinned-copper wire, ⊕ 0.020-in. nickel-clad copper wire, vs. energy output of capacitor-discharge welding power supply in watt seconds. Electrode force 10 lb, contoured as shown in Table 1

tensile strength about 13%. A normal-tensile test proves the weld is as strong as the wire, notwithstanding the fact that the wire is weakened by welding. It does not seem that a joint of 100% efficiency can be produced by the welding process at the present state of the art. Spot checks of the nature just described were made on other materials in this investigation. The schedules developed will yield a true joint strength of 80 to 90% of that in the unaffected wire. A direct-tensile test of the joint will give a value from 50 to 80% of the unaffected wire. Either the wire or joint fails in such a test with about 50-50 distribution. The tensile value is lower when schedules are adjusted to force a 100% wire failure or 100% joint failure. Electronic circuits using this process should be designed so that the maximum load is applied in normal tension as shown in Fig. 12.

90-deg Bend Test

Bend tests were made using the normal and lateral methods, as shown in Fig. 14, on the 0.032-in. tinned copper to 0.30-in. nickel-clad copper wire joint for both 60 cycle a-c and capacitor-discharge welding equipment. These joints had equivalent tensile strength, averaging 20-lb direct tensile. Test results are given in Table 3.

This test was made for the joint having the highest percentage of copper since this combination is most sensitive to excessive collapse, grain growth and residual strains. Reference should also be made at this point to the metallographic samples which bring out differences in crystal structure of the joints above.

Reproducibility

After determining the best set of conditions to produce joints having the maximum tensile strength, a group of 20 samples for each combination was welded on capacitor-discharge equipment.

The variation for each combination was computed as follows:

$$\text{Variation} = \frac{\text{Max} - \text{Min}}{\text{Avg}}$$

The variation for the 14 combinations evaluated ranges from a minimum of 0.162 (0.020-0.020 copper-clad nickel-iron wire to nickel-clad copper wire) to a maximum of 0.348 (0.017 to 0.020 gold-plated nickel-iron-cobalt to nickel-clad copper wire). The average variation is 0.26. The average direct-tensile results compare favorably with the predicted average taken from the tensile vs. energy curves. The maximum and minimum differences are 0.7 and 0.2 lb, respectively, with an average difference of 0.38 lb. The direct-tensile test appears to be the best for checking setups prior to welding at the present time.

Table 3—Bend-test Results—0.032-in. Tinned Copper to 0.030-in. Nickel-clad Copper-wire Joint

Machine type	Wire	Number of 90-deg bends
Normal bend		
Capacitor discharge	0.032 copper	8
Capacitor discharge	0.030 nickel-clad copper	11
60 cycle ac	0.032 copper	7
60 cycle ac	0.030 nickel-clad copper	9.5
Lateral bend		
Capacitor discharge	0.032 copper	10
Capacitor discharge	0.030 nickel-clad copper	12
60 cycle ac	0.032 copper	9
60 cycle ac	0.030 nickel-clad copper	8.5

New Alloys for Brazing Heat-Resisting Alloys

Investigation is undertaken to develop a ductile brazing alloy, or alloys which might possess superior wettability and produce ductile joints with a number of heat-resisting alloys, without reacting excessively with them

BY W. FEDUSKA

Introduction

High-temperature alloy brazing is being utilized to join complex,multi-component assemblies of steam turbines, land gas turbines and components for aircraft, rockets and nuclear reactors. This technique has been advantageous in that numerous joints, often inaccessible to welding operations, can be joined in a single operation. Also, assemblies which have been fabricated by high-temperature brazing are essentially free from distortion and require no postheat treatment for stress relief.

The commonly used brazing alloys, which fulfill most of the requirements for high-temperature brazing, are of the following types: (1) nickel-chromium-silicon-boron-carbon alloys, (2) nickel-chromium-silicon alloys, (3) nickel-silicon-boron alloys, (4) nickel-phosphorous alloys and (5) nickel-phosphorous-chromium alloys. These alloys perform very well in many applications, but may have some disadvantages in certain applications. The nickel-chromium - silicon - boron - carbon alloys, the nickel-silicon-boron and nickel-chromium-silicon alloys can react excessively at brazing temperatures to cause considerable base metal penetration or erosion. If thin (0.020 in. or less) stainless steel or high-temperature alloy components are to be joined, complete base-metal penetration by the brazing-alloy elements may occur. Stringent control of all brazing factors, especially preplacement, may enable large area joints to be prepared on thin sections of high-temperature alloys with these brazing alloys. However, such controls may not always be available in production. Joints to thin-walled stainless steels may be made with little base-metal erosion when nickel-phosphorous or nickel - chromium - phosphorous alloys are used, but the resultant ductility of such brazed joints is low, may be harmful in cyclic stress applications and must be improved by heat treatment. None of the nickel - chromium - silicon - boron - carbon, nickel-chromium-silicon, nickel-silicon-boron, nickel-phosphorous or nickel-chromium-phosphorous alloys can, *per se*, readily wet and adhere to titanium-aluminum bearing alloys or high-aluminum, iron-base alloys. Brazing of titanium-aluminum bearing alloys with nickel-chromium-silicon and nickel-silicon-boron brazing alloys can be accomplished but requires, when surface conditioning is not used, specific conditions of vacuum and temperature[1] which may not always be attainable in production.

Therefore, an investigation was undertaken to develop a ductile brazing alloy, or alloys, which might possess superior wettability and produce ductile joints with various stainless steels, titanium-aluminum bearing alloys or aluminum-iron type alloys, without reacting excessively with these materials. This paper relates the development of such alloys and presents some property data obtained on joints brazed with the best of these alloys.

Theory Related to Developing a Ductile Brazing Alloy

A ductile brazing alloy would be, essentially, a solid-solution alloy (at least 80% solid solution). This alloy would have a matrix free from embrittling intermetallic compounds and would melt within a low brazing-temperature range (preferably 1750 to 2100° F). As a basis in achieving a new low-melting, solid-solution alloy, the nickel-palladium system is attractive. Although palladium is fairly expensive ($24/troy ounce), the small amount of brazing alloy consumed in brazing numerous components makes utilization of this element practical. The elements of this alloy system exhibit complete solid solubility and a minimum melting temperature of 2260° F at a composition of 60% palladium-40% nickel.* Since this melting temperature is still too high and can cause excessive grain growth in base materials, elements should be added, within solubility limits, to lower the liquidus temperature to between 1750 and 2100° F.

Beryllium and silicon are "addition-elements" which have some solid solubility in nickel or palladium and which can be added to a nickel-palladium base to lower its melting temperature. About 2.7% beryllium is soluble at 2116° F in nickel. At 1706° F., 0.06% beryllium is soluble in palladium. Up to 9.3% silicon can remain in solid solution in nickel at 2104° F. Palladium and silicon are mutually insoluble. In the beryllium-palladium system, a 2.1% beryllium addition to palladium produces an eutectic which melts at 1706° F. Addition of 5.7% beryllium to nickel produces eutectics which melt at 1769 and 2116° F. When 15.5, 45 and 58 percentages of silicon are added separately to palladium, eutectics occur at 1328, 1472 and 1562° F., respectively.[2] Therefore, the melting temperature of the 40 nickel-60 palladium alloy can be lowered by adding beryllium and/or silicon. Maximum amounts of these elements which can be added, to produce a low-melting solid-solution alloy, must be determined by experimentation.

In addition to producing an alloy having a melting temperature which will be sufficiently low to serve as a brazing alloy, the presence of pal-

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* All compositions are in weight percentages.

ladium and beryllium in the alloy provides two elements which may facilitate the wetting of titanium and/or aluminum-bearing alloys.

Table 1—Some Metal Vapor-pressure Data

Metal	Temperature, °F, at which vapor pressure is [a] 0.001 mm	0.1 mm
Ag	1718	2164
Be	2066	2543
B	2264	2712
Al	1634	2054
C	4478	5300
Si	2234	2705
Cr	1994	2448
Mn	1614	2018
Fe	2390	2914
Ni	2500	3054
Pd	2561	3198
Au	2402	2996

[a] Data taken from Reference 4.

Table 2—Raw Materials Used in Preparing the Experimental Brazing Alloys

	Purity, %
Palladium sponge	99.99+
Electrolytic nickel	99.90
Pure, crushed beryllium	99.7
Hyperpure silicon, semiconductor grade	99.999+
Electrolytic chromium	99.92

Theory Related to Wettability

Wettability of a base metal by a brazing alloy can be increased in several ways. Increased wettability can occur if the liquid brazing alloy has a low surface tension, $\gamma g\text{-}l$, and if a low interfacial tension, $\gamma\ l\text{-}s$, exists between the liquid brazing alloy and the solid base metal such that:

$$\gamma g\text{-}s > \gamma l\text{-}s + \gamma g\text{-}l \cos\theta \quad (1)$$

where

$\gamma g\text{-}s$ = spreading tension
$\gamma l\text{-}s$ = interfacial tension, liquid brazing alloy to solid base metal
$\gamma g\text{-}l$ = surface tension of the liquid brazing alloy
θ = contact angle between the liquid brazing alloy and the base-metal surface

The surface energies of palladium and beryllium, at their melting temperatures, have been estimated at 1280 and 1620 ergs/cm², respectively.[3] Excluding surface concentration effects, only the palladium appears attractive in lowering the surface energy of the liquid brazing alloy, from a value of 1570 to 1615 ergs/cm²[3] reported for nickel. Therefore, an increased wettability of titanium and/or aluminum-bearing alloys, may be achieved due to a decrease in liquid-brazing-alloy surface energy, produced by the presence of palladium.

The presence of beryllium in the nickel-palladium base should facilitate incipient alloying (by rapid diffusion) with the base metal. This incipient alloying by beryllium, which constitutes wetting of of the base metal, may increase the interfacial tension between the brazing alloy and the base metal, while decreasing the surface tension of the resultant brazing-alloy composition, such that the condition of eq 1 would still prevail. These effects by beryllium and the previous effect of palladium may cause an increase in wettability, of titanium and/or aluminum-bearing alloys, according to the conditions of eq 1.

Partial vaporization by beryllium from a brazing alloy in a vacuum environment is another factor which may contribute toward the improved wettability of an alloy containing titanium and/or aluminum. In Table 1, the vapor-pressure data of various elements which are present in high-temperature base metals and brazing alloys have been listed.[4] Beryllium has a higher vapor pressure than palladium and can partially vaporize during brazing. The beryllium vapor may then react with films on the base-metal surface, or "getter" trace contaminators in the environment surrounding the hot base metal. Wetting of this clean, protected base metal may then be readily accomplished by the

Table 3—Chemical Compositions of Base Metals and Commercial Brazing Alloys Which Were Used in the Various Experiments

Base alloy	Description	Composition, weight percentages: Fe	Ni	Cr	Co	Ti	Al	W	C	B	Other
AISI 304	Stainless steel	Bal.	8.00–11.00	18.0–20.0	...	...	...	...	0.08 max	...	2 Mn
AISI 316	Stainless steel	Bal.	10.0–14.0	16.0–18.0	...	...	...	...	0.10 max	...	2.00–3.00 Mo
AISI 347	Stainless steel	Bal.	9.0–13.0	17.0–19.0	...	...	...	...	0.08	...	0.80 NbTa min
Alloy 4	Fe-base, Ti-hardened alloy	Bal.	26.0	13.5	...	1.6	0.1	...	0.03	...	8 Mn, 3 Mo, 0.8 Si
Alloy 5	Ni-base, Ti-hardened alloy	7.0	Bal.	15.0	...	2.5	0.9	...	0.04	...	0.7 Mn, 3 Si 0.9 NbTa
Alloy 6	Co-base, high-damping alloy	...	23	...	Bal.	2.0	0.2	...	...	...	0.5 Mn, 1 Zr, 0.3 Si
Alloy 7	Cast Ni-base alloy	...	Bal.	12	...	0.50	6.00	...	...	...	4.5 Mo, 2.00 Nb
Alloy 8	Cast Ni-base alloy	...	Bal.	12	10	4	4	8	0.10	0.05	0.05 Zr
Alloy 9	Fe-base-Al alloy	Bal.	...	...	...	...	15.8	...	...	...	...
Alloy 10	Fe-Al-Cr alloy	Bal.	...	24.7	3.0	...	4.93	...	...	...	...
Alloy 11	Fe-Al-Cr Alloy	Bal.	...	7.82	...	...	8.24	...	...	0.05	0.2 Zr

Brazing alloy no.	Type	Chemical composition, weight percentages: Ni	Cr	Si	B	C	P	Ag	Mn	Fe
10	Ni-Cr-Si-B-C	Bal.	13.67	4.60	3.13	0.76	..	...	...	4.29
11	Ni-Cr-Si	Bal.	19.00	11.25	...	0.03	..	...	...	1.10
12	Ni-Si-B	Bal.	...	4.58	2.89	...	..	...	...	...
13	Ni-P-Cr	Bal.	13	...	...	...	10	...	...	...
14	Ag-Mn	...	...	...	...	...	..	85.0	15.0	...

Table 4—Compositional and Structural Data on Experimental Nickel-palladium Brazing Alloys

Brazing alloy	Nominal composition, weight ,% Ni	Si	Be	Cr	Pd	Estimated per cent solid solution in microstructure
1	40.0 (40.1)[a]	0.5 (0.46)	...	...	59.5	95–97
2	39.5	1.5 (1.40)	...	...	59.0	90
3	38.5	3.0	...	...	58.5	40
4	40.0 (40.7)	...	0.25 (0.30)	...	59.75	93–95
5	40.0 (41.1)	...	0.5 (0.66)	...	59.5	90
6	40.0 (41.7)	...	1.0 (1.15)	...	59.0	50
7	35.84	0.25	0.15	10.0	53.76	90–95
8	29	...	...	28	43	~100
9	40.0 (44.3)	0.50 (0.49)	0.25 (0.25)	...	59.25 (54.96)	90–95

[a] Actual compositions in parentheses.

liquid brazing alloy, by superficial alloying of the nickel, palladium, silicon and remaining beryllium with the base alloys.

From these considerations, a solid-solution brazing alloy containing nickel, palladium and small concentrations of beryllium and/or silicon, constitutes a different brazing-alloy type with a capability of bonding to high-temperature alloys without excessive base-metal erosion, an ability of producing ductile brazed joints and a potential of wetting and adhering to titanium and/or aluminum-containing alloys. In this paper, the results obtained in developing such nickel-palladium base brazing alloys are presented.

Materials

Table 2 lists the purity of the elements used in preparing the experimental brazing-alloy compositions. In Table 3, the various commercial brazing-alloy compositions, which were used for comparison with the experimental alloys, are listed, in addition to the various base metals which were used for wetting tests, shear tests and bend tests.

Procedure

Elements of each particular experimental alloy were weighed and charged, as powder or chunks, into a cylindrical die. Each 50 g of alloy "mixture" was compacted at 50-tons pressure to produce a briquette about 1/2 in. thick and 2 in. in diam.

This briquette was then charged into a nonconsumable, tungsten-electrode melting furnace. The alloy briquettes were preplaced into troughs in a cooled copper block and were melted by a nonconsumable tungsten electrode. In this experiment, the nickel-palladium alloys were melted in helium, three times on the top face of each original compact and three times with the bottom face of the compact in the top position. After these melting steps, each face of the melted "button" was "dressed up," i.e., each face was melted with considerable stirring of the liquid pool by the arc to insure complete alloy homogenization. A pure titanium "scavenging" button was melted before and during the melting of each of the experimental alloy buttons to remove trace impurities from the helium atmosphere. The compositions of the alloy buttons which were prepared by this method are listed in Table 4. Two compositions, alloys 7 and 8, also contained chromium as an addition element to lower the melting-temperature range of the nickel-palladium base.

After the alloys had been prepared, their melting-temperature ranges were determined by the cooling-curve technique. About one-fourth of each alloy button was used for these tests. The alloy piece was positioned in an alundum boat which was surrounded by a molybdenum susceptor. This entire assembly was placed in a Vycor tube and surrounded by an induction heating coil. A platinum to platinum-rhodium thermocouple, coated at its bead with zirconia wash, was used to measure the molten-bath temperatures. After the thermocouple had been positioned, the Vycor tube was sealed and evacuated to about 0.1 micron of mercury pressure. Three cooling-curve runs were made on each alloy and the liquidus and solidus temperatures were averaged from data obtained in these runs.

When the melting temperature ranges of the experimental alloys had been ascertained, the resultant rod-shaped pieces, 1/4 to 3/8 in. in diam by 3/4 in. long, were sectioned to provide specimens for the determination of the brazing alloy microstructures and microhardnesses.

Table 5—Liquidus-solidus Temperature Ranges Exhibited by the Various Experimental Brazing Alloys

Brazing alloy	Melting temperature range[a] Liquidus temperature, °F	Solidus temperature °F	ΔT, °F liquidus-solidus	Δ T,° F NiPd minimum-liquidus of alloy
1	2200	2145	55	−60
2	2100	2020	80	−160
3	2010	1780	230	−250
4	2210	2130	80	−50
5	2155	2050	105	−105
6	1985	1770	215	−275
7	2210	2140	70	−50
8	2280	2220	60	+20
9	2120	2040	80	−140

[a] Average values from three cooling-curve runs.

The remainder of the fused rods of the most promising alloys was used in experiments aimed at establishing the workability of the alloys into strip stock. Generally, the alloys were processed down from cast-pin sections, about 1/4 to 3/8 in. in diam by 1/2 in. long, to strip stock. The workable alloys were hot pressed, at about 1650° F, down to 1/8- to 1/4-in. thick "slabs." The alloys were heated by a reducing oxyacetylene flame, prior to the hot-working operations. The "slabs" were then hot rolled, at about 1650° F. using reductions of approximately 0.025 in. per heating, down to 1/16-in. thick strip. This strip was then cold rolled down to 0.006- to 0.020-in. thick strip. Fine filings were also prepared from some of the alloys and used in wetting tests.

Wettability-test specimens were then prepared from various base materials and wettability tests were performed in the same manner as previously reported.[5] In this investigation, all wettability tests were run in a vacuum environment of about 0.05- to 0.07 microns of mercury pressure, at temperatures about 90° F above observed melting temperatures. After the wettability tests had been completed,

Table 6—"As-cast" Experimental Brazing-alloy Microhardness Data (Knoop Hardness Values, KHN, Were Obtained at 25-g Load, Using a 10.25-mm Objective Lens)

Brazing alloy no.	Average hardness values, KHN: Matrix	Average hardness values, KHN: Other phase(s)	Equivalent Rockwell hardness: Matrix	Equivalent Rockwell hardness: Other phase(s)
1	196	318[a]	88 R_B	31 R_C[a]
2	218	387[a]	10 R_C	38 R_C[a]
3	265	247[b]	23 R_C	19 R_C[b]
4	254	335[a]	21 R_C	34 R_C[a]
5	313	349[a]	31 R_C	35 R_C[a]
6	329	284[b]	32 R_C	28 R_C[b]
7	230	262[c]	15 R_C	22 R_C[c]
8	201	359[d]	90 R_B	36 R_C[a]
9	259	327[a]	21 R_C	32 R_C[a]

	Commercial brazing-alloy type	Average hardness, KHN	R_C equivalent
10	Ni-Cr-Si-B-C	742–805	63–65
11	Ni-Cr-Si	750–775	63–65
12	Ni-Si-B	646	58
13	Ni-P	672	60
14	Ag-Mn	61	...

[a] Eutectic region.
[b] Primary solid solution.
[c] Intermetallic compound.
[d] Unresolved background phase.

Table 7—Brazed-joint-interface Microhardness Data Obtained on AISI 304 Brazed with Brazing Alloy 9 at 1995° F (Knoop hardness values, KHN, were obtained at 25-g load, using a 10.25-mm objective lens)

	KHN	Equivalent Rockwell hardness
Base metal	176	83 R_B
Interface	168	76 R_B
Brazing alloy	261	22 R_C
Brazing-alloy matrix	231	15 R_C

wetting-index data were obtained from solidified contact angle and spreading area measurements, as previously reported.[5] When these data had been accumulated, lap joint test specimens, of base metals AISI 304, 316, Alloy 4, Alloy 5, Alloy 8, were brazed in vacuum with brazing Alloy 9, and tested at room temperature. Bend tests were also prepared by brazing the single-lap joint specimens of the same base alloys, at a joint overlap of $3t$. These samples were then bent around a loading tool having a 10 mils radius at the loading edge.

Elevated-temperature shear-test data were then obtained on one of the base alloys, using the most promising composition of the nickel-palladium base brazing alloys. In these tests double-lap joints were prepared from cast, nickel-base, high-temperature Alloy 8, by brazing with experimental brazing Alloy 9 (see Table 4).

After wettability and strength data had been obtained on the nickel palladium brazing alloys, a microscopic and microhardness examination was made of some of the brazed-joint interfaces.

Results and Discussion

The results obtained in the different phases of this investigation are separately discussed.

Melting-temperature Ranges

Table 5 gives the experimentally-determined melting temperature ranges of the brazing alloys. Of these alloys, brazing Alloy 3 (melting range of 1780 to 2010° F) and brazing Alloy 6 (melting range of 1770 to 1985° F) exhibited the greatest lowering of the liquidus temperature below that of the nickel-palladium minimum temperature of 2260°F.

The chromium additions to brazing alloys 7 and 8 did not produce a lowering of the melting temperature range. It was felt that a ternary eutectic composition might exist in the nickel-palladium-chromium system. Chromium-palladium and chromium-nickel exhibit eutectics at 2408 and 2450° F, respectively, and chromium-palladium and nickel-palladium exhibit minima at 2370 and 2260° F.[2] Therefore, an alloy addition of 10% chromium was made to brazing Alloy 7 to lower its liquidus temperature. Brazing Alloy 8, a composition extrapolated to be near a ternary eutectic of the nickel-chromium-palladium system, was also prepared. Brazing Alloy 7 showed a slight lowering of the liquidus temperature (50° F decrease) while brazing Alloy 8 did not approach a ternary eutectic composition and actually possessed a liquidus temperature of 2280° F, which was 20° F greater than the melting temperature of the 60 palladium-40 nickel alloy.

Microstructures and Microhardnesses of Brazing Alloys

In Fig. 1 through 3, the "as-cast" microstructures of the nine experimental brazing alloys have been presented. Brazing alloys 1, 2, 4, 5, 7, 8 and 9 contained 80 to 100% solid-solution matrices, as desired.

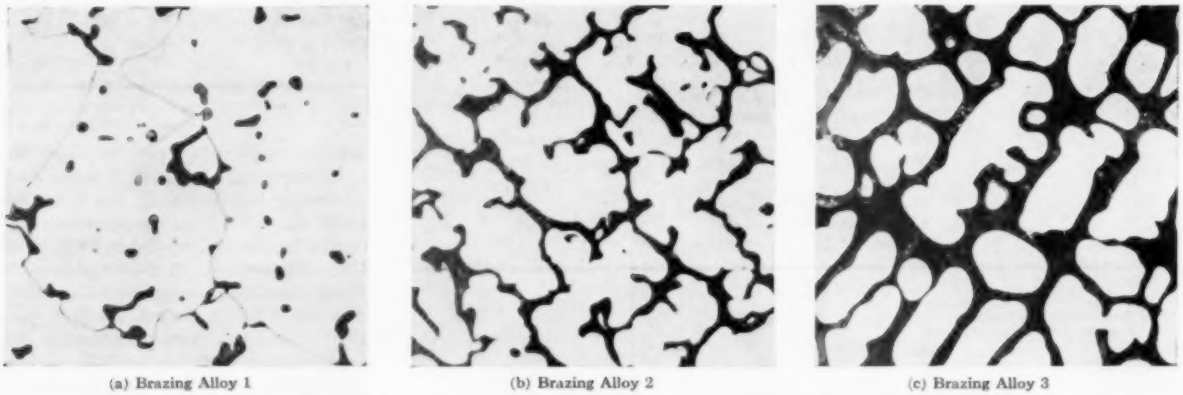
Brazing alloys 3 and 6 contained silicon or beryllium in such excess that eutectic matrices, containing hard silicides or beryllides, formed in these materials. Nickel and silicon form numerous intermetallic compounds. However, at the low silicon concentrations employed in preparing the experimental alloys, the presence of a nickel-silicon intermetallic does not seem likely, due to the high solubility of silicon in nickel (about 5 weight percent at room temperature). Palladium and silicon exhibit mutual insolubility and form low-melting intermetallic compounds—Pd_2Si, PdSi and, possibly, Pd_3Si_2 at 2282, 2010 and about 1740° F, respectively. Therefore, the intermetallic compound phase in brazing alloys 4 to 6 should be a palladium-silicon type, possibly Pd_3Si_2.[2] According to Hansen, $BePd_3$, $BePd_2$, Be_2Pd_3 can form at temperatures of 1760, 1990 and 2140° F, respectively. BeNi and $Be_{21}Ni_5$ can form at 1472 and 2308° F, respectively. Since the beryllium concentrations employed in making the alloys were 1% and less, and a maximum temperature of about 2370° F was used in melting these alloys, the intermetallic compound was probably of the beryllium-palladium type, most likely, $BePd_3$.

The hardnesses of the matrices of the experimental alloys, containing 90 to 100% solid solution, varied from 88 R_B for brazing Alloy 1 to 31 R_C for brazing Alloy 5. Brazing alloys 3 and 6, having eutectic matrices which contained silicides or beryllides, possessed slightly higher average matrix hardnesses—23 R_C for Alloy 3 and 32 R_C for brazing Alloy 6. A maximum hardness of 38 R_C was obtained on regions containing the silicide intermetallic phase in brazing alloys 1 to 3, while a maximum value of 35 R_C was obtained on the beryllium-bearing, intermetallic-

compound-phase regions in brazing alloys 4 to 6 (see Table 6). Significantly, the hardness values of all the phases in the 9 experimental alloys were much lower than the hardnesses obtained on hard, brittle, commercial high-temperature brazing alloys (58 to 65 R_C, as indicated in Table 6). Based on both low hardness and low-melting-temperature range, brazing alloys 1, 2, 4, 5 and 9 appeared most attractive of the 9 alloys prepared for producing ductile brazing alloys.

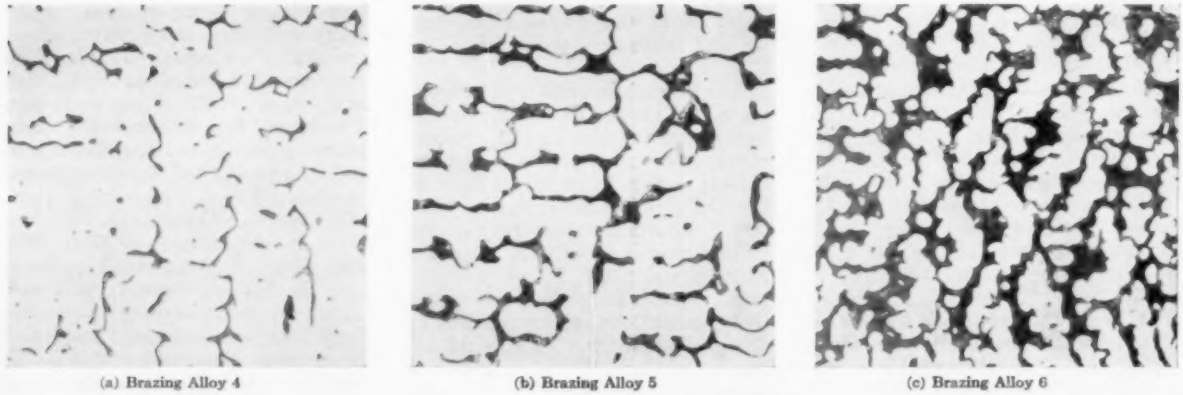
Workability

The workability of all alloys, except the high-melting range brazing alloys 7 and 8, was determined. Pieces of brazing alloys 1, 2, 4, 5 and 9 weighing about 10 g, were successfully worked into strip stock varying from 0.006 to 0.020 in. in thickness. Edge tearing occurred during the initial upsetting of these small pieces. These tears prevailed throughout the rolling of the pieces but, significantly, did not propagate across the strip. The edge tearing, during upsetting, could be relieved



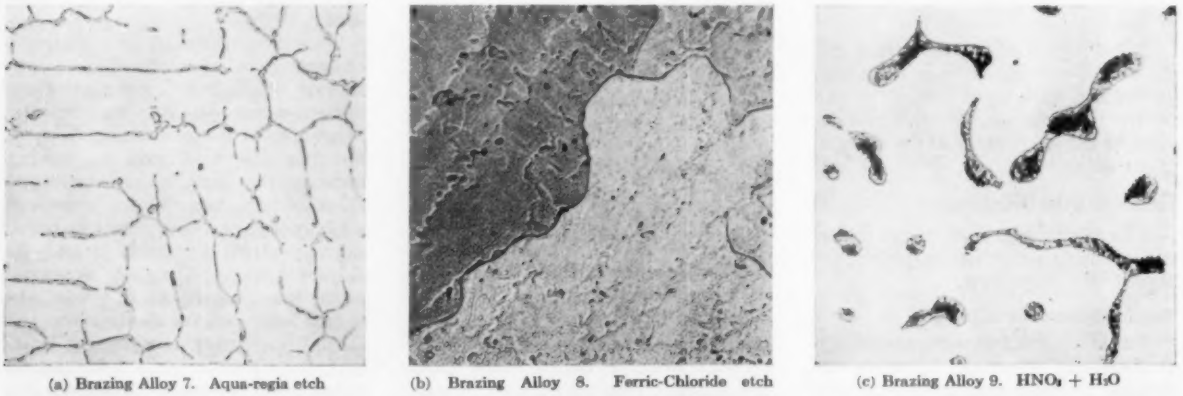
(a) Brazing Alloy 1 (b) Brazing Alloy 2 (c) Brazing Alloy 3

Fig. 1—"As-cast" microstructures of some experimental nickel-palladium-silicon brazing alloys. Etched in $HNO_3 + H_2O$. ×250 (Reduced by 25% upon reproduction)



(a) Brazing Alloy 4 (b) Brazing Alloy 5 (c) Brazing Alloy 6

Fig. 2.—"As-cast" microstructures of some experimental nickel-palladium-beryllium brazing alloys. Etched in $HNO_3 + H_2O$. X 250 (Reduced by 25% upon reproduction)



(a) Brazing Alloy 7. Aqua-regia etch (b) Brazing Alloy 8. Ferric-Chloride etch (c) Brazing Alloy 9. $HNO_3 + H_2O$

Fig. 3—"As-cast" microstructures of some experimental nickel-palladium brazing alloys. X 250 (Reduced by 25% upon reproduction)

by using larger ingots (from 1 to 5 lb) so that the rate of temperature drop would be reduced and the working temperatures could be more closely controlled. Also, a more suitable initial ingot structure would be available for initial breakdown of the material. Brazing Alloy 3, containing an eutectic, rather than a solid-solution matrix, broke up in the initial upsetting operation while brazing Alloy 6, also containing an eutectic matrix, shattered during processing down to strip stock.

On the basis of melting-temperature range, matrix hardness, distribution of eutectic islands in the cast condition and workability, brazing alloys 1, 2, 4, 5 and 9 represented promising, ductile brazing-alloy compositions. Of these alloys, brazing Alloy 9, containing 0.25 Be, 0.49 Si, 44.3 Ni and 54.96 Pd, possessed the best combination of melting-temperature range, narrow liquidus-solidus temperature spread, eutectic island distribution and workability. This alloy melted in the temperature range of 2040 to 2120° F.

This melting-temperature range, although suitable, *per se*, for brazing high-temperature alloys, was slightly higher than desirable in order that excessive grain growth might be prevented in thin-walled stainless steel tubing or strip. From previous experimentation in brazing thin-walled stainless-steel tubing, a short-time brazing cycle of 5 min. in the range of 1920 to 2010° F was found to produce very little grain coarsening in AISI 316 base metal.[6] Therefore, an additional lowering of the brazing-temperature range was required, down to the 1920 to 2010° F brazing-temperature level, in order that brazing Alloy 9 might also be useful for brazing stainless steels.

Theory on High-temperature Brazing Alloy—Base-metal Reactions

High-temperature alloy brazing is a liquid-solid interdiffusion reaction, in which elements present in the liquid brazing alloy diffuse into the solid base metal while base-metal elements migrate into the liquid brazing alloy. Usually, solution of base-metal elements will occur only after liquid brazing alloys have been heated above their liquidus temperatures, and the presence of high-melting-temperature base-metal elements effects an increase in the melting temperature range of the resultant brazing-alloy composition. However, the brazing-alloy elements, due to their diffusion into the base metal during heating to brazing temperature, may produce a low-melting solid solution or

Table 8—Vacuum Wettability-test Data Obtained on Various Stainless and Heat-resisting Alloys

Run no.	Solidified contact angle, θ, deg	Wetted area A, sq. in.	Wetting index, WI = A cos θ[a]	Wettability-test combination
W284	→0	0.74	0.7	AISI 304-brazing Alloy 9
W285	2	1.32	1.3	AISI 347-brazing Alloy 9
W286	→0	0.39	0.4	AISI 316-brazing Alloy 9
W268	→0	0.70	0.7	Base Alloy 4-brazing Alloy 9
W269	3.5	0.55	0.5	Base Alloy 5-brazing Alloy 9
W270	5.5	0.68	0.7	Base Alloy 6-brazing Alloy 9
W275	3.5	0.47	0.5	Base Alloy 7-brazing Alloy 9
W267	5.5	0.41	0.4	Base Alloy 8-brazing Alloy 9
W263	8.5	0.18	0.2	Alloy 8-brazing Alloy 10
W264[b]	→0	0.07	0.07	Alloy 8-brazing Alloy 11
W277	3.0	0.33	0.3	Base Alloy 11-brazing Alloy 9
W276	6.5	0.27	0.3	Base Alloy 10-brazing Alloy 9
W256	11.0	0.25	0.2	Base Alloy 10-brazing Alloy 12
W278	10.5	0.22	0.2	Base Alloy 9-brazing Alloy 9
W255	7.0	0.19	0.2	Base Alloy 9-brazing Alloy 14
W251	10.0	0.16	0.2	Base Alloy 9-brazing Alloy 11
W257	7.5	0.18	0.2	Base Alloy 11-brazing Alloy 12
W258	17.0	0.15	0.1	Base Alloy 9-brazing Alloy 12
W252	20.0	0.16	0.1	Base Alloy 10-brazing Alloy 11
W250	28.5	0.15	0.1	Base Alloy 11-brazing Alloy 11
W253	12.5	0.08	0.08[c]	Base Alloy 10-brazing Alloy 14
W249	20.0	0.08	0.07	Base Alloy 9-brazing Alloy 10
W247	29.0	0.05	0.05[c]	Base Alloy 10-brazing Alloy 10
W254	35.0	0.05	0.04	Base Alloy 11-brazing Alloy 14
W248	...	...	..[a]	Base Alloy 11-brazing Alloy 10

[a] Wetting index ratings: 0.5 excellent; 0.3–0.4 very good; 0.2 good; 0.1 fair; and <0.1 poor.
[b] Brazing alloy eroded through base metal.
[c] Dewetted.

Table 9—Room-temperature Lap-joint Shear Strength and Bend-test Data Obtained on Various Base Metals Joined with Brazing Alloy 9

Base metal	Average shear strength, psi	Remarks
Lap-joint results		
AISI 304	22,900	Single-lap, 3t overlap
AISI 316	21,400	Single-lap, 3t overlap
Alloy 4	46,700	Double-lap, 1t overlap
Alloy 8	49,200	Double-lap, 1t overlap
Bend-test results		
	Bend, deg	
AISI 304	180 (avg.)	Did not break, 3t overlap
Alloy 4 (run 28)	170	Did not break, 3t overlap
Alloy 5 (run 29)	170	Did not break, 3t overlap
Alloy 6 (run 30)	170	Did not break, 3t overlap
AISI 304 (run 27) brazed with brazing alloy 13	45	Broke in joint, 3t overlap

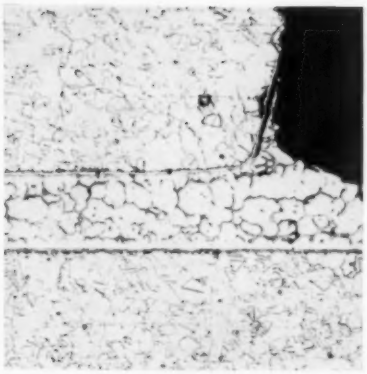


Fig. 4—Nature of AISI 304 joint-interface region when brazed with brazing Alloy 9 at 1995° F. Note fine grain size in base metal. X 100. (Reduced by 25% upon reproduction)

eutectic-alloy composition in the base metal. When this reaction occurs during heating, the "altered composition" base metal may begin to fuse. As the diffusion reaction continues across the liquid-solid interface, the brazing alloy composition then becomes enriched in base-metal elements and, being an "altered composition" brazing alloy, will exhibit a different melting temperature range. If the diffused base-metal elements are present in favorable concentrations in the brazing alloy, a low-melting solid solution or complex-eutectic will eventually form below the melting temperature of the original brazing-alloy composition.

Reaction of Brazing Alloy 9 with Various Stainless Steels

To determine whether or not a low-melting solid solution or complex eutectic might form, brazing Alloy 9 was heated in vacuum, in contact with clean plates of AISI 304 and AISI 316 stainless steels. With interdiffusion occurring, a favorable, lower-melting eutectic or solid-solution composition might be produced which would, in effect, produce a liquid brazing alloy at a much lower melting-temperature range. Such a reaction actually occurred, within seconds, after heating brazing Alloy 9 to 1920° F in contact with AISI 304 and to 1985° F in contact with AISI 316. These temperatures were within the inhibition requirements for grain growth in brazing these materials, and were 54 to 118° F below the solidus temperature of brazing Alloy 9.

The lowering of the melting temperature of brazing Alloy 9, in contact with AISI 304, must be attributed to a pickup of iron, chromium, manganese and carbon from this base material, and the

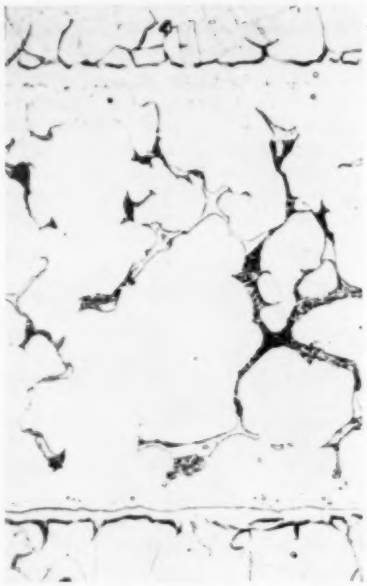


Fig. 5—Brazed-joint interface microstructure produced by reaction at 1995° F of brazing Alloy 9 with AISI 304 base metal. Compare resultant brazing-alloy microstructure with original brazing Alloy 9 structure in Fig. 3c. A similar interface structure was produced by reaction of brazing Alloy 9 with AISI 316. Note fine grain size in base metal. Etched in Marble's Reagent + HNO_3. X 500 (Reduced 40% upon reproduction).

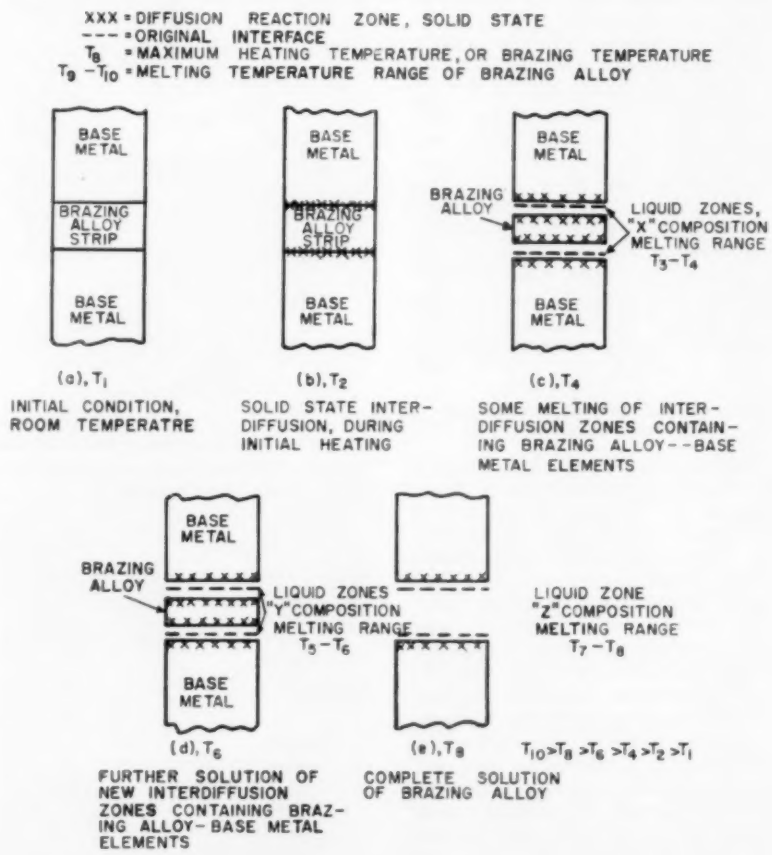

XXX = DIFFUSION REACTION ZONE, SOLID STATE
--- = ORIGINAL INTERFACE
T_8 = MAXIMUM HEATING TEMPERATURE, OR BRAZING TEMPERATURE
$T_9 - T_{10}$ = MELTING TEMPERATURE RANGE OF BRAZING ALLOY
BASE METAL
BRAZING ALLOY STRIP
BASE METAL
(a), T_1
INITIAL CONDITION, ROOM TEMPERATRE
BASE METAL
BRAZING ALLOY STRIP
BASE METAL
(b), T_2
SOLID STATE INTER-DIFFUSION, DURING INITIAL HEATING
BASE METAL
BRAZING ALLOY
LIQUID ZONES, "X" COMPOSITION MELTING RANGE $T_3 - T_4$
BASE METAL
(c), T_4
SOME MELTING OF INTER-DIFFUSION ZONES CONTAINING BRAZING ALLOY--BASE METAL ELEMENTS
BASE METAL
BRAZING ALLOY
LIQUID ZONES "Y" COMPOSITION MELTING RANGE $T_5 - T_6$
BASE METAL
(d), T_6
FURTHER SOLUTION OF NEW INTERDIFFUSION ZONES CONTAINING BRAZING ALLOY-BASE METAL ELEMENTS
LIQUID ZONE "Z" COMPOSITION MELTING RANGE $T_7 - T_8$
(e), T_8
COMPLETE SOLUTION OF BRAZING ALLOY
$T_{10} > T_8 > T_6 > T_4 > T_2 > T_1$

Fig. 6—Stages of the interdiffusion reactions between AISI 304 and AISI 316 and brazing Alloy 9

formation of a low-melting solid solution or complex eutectic from a combination of one or several of these elements with brazing Alloy 9 elements. The fact that the brazing Alloy 9-AISI 316 liquid formation reaction was higher than that of brazing Alloy 9-AISI 304 may be due to the pickup of molybdenum from AISI 316 by the brazing alloy. Molybdenum melts at a high temperature, 4260° F, and its presence would tend to increase the melting temperature of the liquid brazing alloy.

Similar tests were tried in which a 40 nickel-60 palladium alloy was heated in contact with AISI 304 and AISI 316. These samples were heated to 2040 to 2060° F with no melting occurring. Therefore, silicon and/or beryllium were essential to the formation of the complex eutectic or low-melting solid solution.†

To determine the qualitative nature of the reaction(s) which transpired when brazing Alloy 9 was heated in contact with AISI 304 and AISI 316, transverse sections from several brazed lap-joint specimens were prepared for microscopic examination. The resultant reaction structures are illustrated in Figs. 4 and 5. In Fig. 4, a fillet formed at the edge of the joint overlap region due to the formation of considerable liquid phase by the interaction of base metal-brazing alloy elements at the brazing temperature (1995° F). The base metal possessed a fine grain size after this brazing experiment. In Fig. 5, the resultant brazed-joint interface microstructure, produced by reactions of brazing Alloy 9 with AISI 304 base metal at 1995° F, is indicated. A faint, pink-colored, solid-solution region (suggesting the presence of beryllium) had formed at the brazing alloy—base metal interface. The hardness of this solid solution was 76 R_B with AISI 304 base metal and 28 R_C with AISI 316 base metal (see Table 7).

Apparently, during the heating of brazing Alloy 9 in contact with AISI 304 and AISI 316, the beryllium and/or silicon diffuse rapidly into the base metal. The decrease in matrix hardness of the brazing Alloy 9 from 21 R_C to 15 R_C indicates that some beryllium and silicon have diffused into the base metal (see Tables 6 and 7). Volume, and some grain-boundary diffusion, can be observed in Fig. 5, at the base-metal interface. When these diffusing elements reach certain concentrations in the base metal, the resultant solid-solution composition, having a reduced melting-temperature range, then fuses. From this liquid zone, dissolved base-metal elements can diffuse into the unfused brazing alloy and brazing alloy elements can diffuse across the new base-metal interface to produce new, low-melting solid-solution composition regions. The new, low-melting solid-solution regions can then dissolve, as heating is continued, into the existing liquid. This "attack" process can continue, with base-metal solution and brazing-alloy solution continually occurring until the interface is entirely molten at a temperature below the melting temperature of the brazing alloy. The probable nature of these reactions has been schematically illustrated in Fig. 6. Upon solidification, a solid solution interface results and the brazing alloy structure (divorced binary eutectic and ternary eutectic in a solid-solution matrix) can be seen to differ from the original brazing Alloy 9 cast structure (compare Figs. 3c and 5). This structural difference is due to the change in composition of the brazing alloy, produced by solution of the base-metal elements into the liquid brazing alloy and diffusion of brazing alloy elements into the base metal at elevated temperature. The filleting-effect at the edges of the joint overlap regions, in Fig. 4, is evidence of the molten condition of the resultant brazing-alloy composition. Note that little base-metal erosion has occurred. Since both beryllium and silicon can effectively lower the melting temperature of the AISI 304 and AISI 316, and their relatively small atomic diameters should impart some mobility to their diffusion into the base metal, these elements must be primarily responsible for the resultant reactions during heating and at brazing temperatures.

Spectrographic analysis indicated that palladium, iron, chromium, nickel, manganese and beryllium are present in the diffusion reaction zone at the final brazing alloy–base metal interface shown in Fig. 5. These findings substantiate the diffusion of beryllium into the base metal, as predicted. The brazing-alloy solid-solution matrix contained

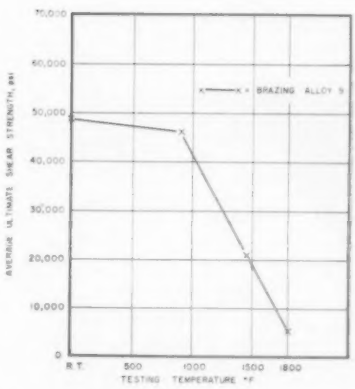


Fig. 7—Effect of temperature on lowering the shear strength of base Alloy 8 joints brazed with brazing alloy 9

nickel, palladium, iron, chromium, copper and beryllium. The presence of iron, copper and chromium in the joint was produced by base-metal solution during brazing.‡ X-ray diffraction analyses of the eutectic islands were not attempted, since these regions were too small to permit proper sample concentration, by using the microdrilling technique.

Wettability-test Results

In Table 8 the results obtained in the wetting of various high-temperature alloys by brazing Alloy 9 are presented. For comparison, some results obtained in wetting some of the same base materials with several commercial brazing alloys have been included. These data indicate superior wetting was obtained with brazing Alloy 9 on all the base alloys tried—AISI 304, AISI 347, AISI 316 and base alloys 4, 5, 6, 7, 8, 9, 10 and 11. In the vacuum environment, Alloy 9 produced better wetting of Alloy 8 than commercial brazing alloys 10 and 11, and produced better wetting of aluminum-containing alloys 9, 10 and 11 than commercial brazing alloys 10, 11, 12 and 14. Sound, crack-free joints have been produced on assemblies of iron-aluminum Alloy 11, brazed with Alloy 9.

Shear-strength and Bend-test Data Obtained at Room Temperature on Stainless Steel and High-temperature Alloys

In Table 9, the shear-strength and bend-test data obtained on stainless-steel joints brazed with brazing Alloy 9 have been summarized. These tests show that considerable shear strength may be realized in

† A lowering of the melting temperatures of brazing alloys 1, 2, 4 and 5 was also noted when these alloys reacted with AISI 304. During these tests, brazing Alloy 1 was liquid at 2010° F, 130° F below its solidus temperature; brazing Alloy 2 was liquid at 1960° F, 60° F below its solidus; brazing Alloy 4 was liquid at 2010° F, 120° F below its solidus; and brazing Alloy 5 was liquid at 1885° F, 160° F below its solidus. In contact with base alloys 5 and 6, brazing Alloy 9 was liquid at 1920° F, 120° F below its solidus temperature. No change in melting temperature was evident when brazing Alloy 9 reacted with base alloys 4, 7, 8, 9, 10 and 11.

‡ Copper was a "tramp" element in the AISI 304 base metal.

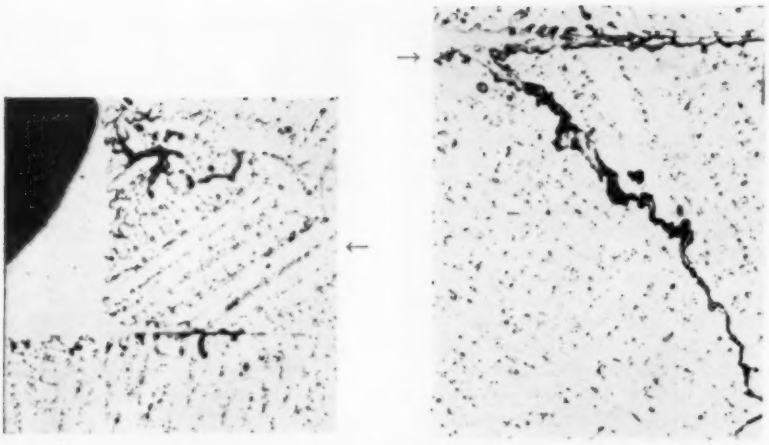


Fig. 8—Joint-interface microstructure produced when brazing Alloy 9 reacts with base Alloy 8. Note grain-boundary penetration by brazing-alloy elements. Arrows indicate the plane of the joint interface. Etched in Fry's reagent. X 100. (Reduced by 45% upon reproduction)

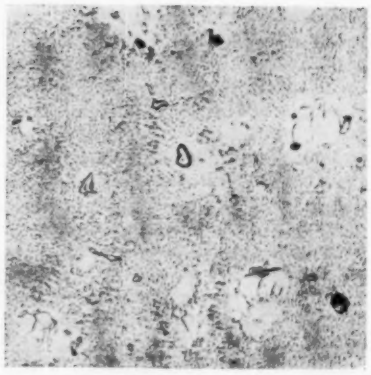


Fig. 9—"As-cast" microstructure of base Alloy 8. Etched in Fry's reagent X250

single-lap joints brazed with brazing Alloy 9, averaging 22,900 psi for AISI 304, 21,400 psi for AISI 316, 46,700 psi for base Alloy 4 and 49,200 psi for base Alloy 8. Also, excellent room-temperature ductilities were obtained on those single-lap joints brazed with Alloy 9 which were bend tested. Yielded, but uncracked, brazed joints were observed in AISI 304, Alloy 4, Alloy 5 and Alloy 6 base metals, after bends varying from 170 and 180 deg were obtained in these tests. In contrast, bend test 27, an AISI 304 single-lap joint specimen which was joined with brazing Alloy 13, failed through the joint interface after being deflected 45 deg. Nickel-phosphorous-chromium brazing alloy (Alloy 13) is notoriously brittle in the "as-brazed" condition. The results of bend test 27 substantiate the inherent brittleness of joints "as-brazed" with this alloy.

Evaluation of Elevated-temperature Shear Strength of Brazing Alloy 9

Table 10 lists the shear-strength data which were obtained at elevated temperature on base Alloy 8 double-lap joints. These data, which are plotted in Fig. 7, show that brazing Alloy 9 produced brazed joints at room temperature which averaged 49,200 psi in shear strength, while at 1000° F the average shear strength of brazing Alloy 9 was 46,400 psi. At 1500° F, brazing Alloy 9 produced joints with base Alloy 8 which averaged 20,600 psi in shear strength. At 1800° F, joints of base Alloy 8 brazed with Alloy 9 were weakened severely, exhibiting an average shear strength of only 4800 psi.

Table 10—Elevated-temperature Shear-strength Data Obtained on Base Alloy 8 Double-lap Joints Brazed with Brazing Alloy 9

Testing temperature, ° F	Average ultimate shear strength, psi
1000	46,400
1500	20,600
1800	4,800

Microscopic and Microhardness Evaluation of the Base Alloy 8 Brazed Joints

A microscopic examination was made of some of the joint-interface regions of the brazed specimens.

In Fig. 8, the joint-interface microstructures, produced when brazing Alloy 9 reacted with cast, nickel-base Alloy 8, have been presented. Extensive grain-boundary diffusion by brazing-alloy elements has occurred, as shown by the grain-boundary penetration and reaction products of Fig. 8. Since the reaction product appears to be primarily a nickel-palladium rich solid solution in the joint-interface region, the diffusion into the grain boundaries must have been due to rapid diffusion of beryllium and silicon of the brazing alloy. Such penetrations have not been observed when brazing Alloy 9 reacts with wrought materials, as Alloy 9, Alloy 10, Alloy 11, AISI 304 and AISI 316. Extensive irrigation of beryllium and silicon from the grain boundaries and into the Alloy 8 grains also must have occurred, since the base-metal structure near the joint no longer resembled the original Alloy 8 structure, as shown in Fig. 9.

Conclusions

1. Low-melting nickel-palladium base brazing alloys, containing additions of beryllium and/or silicon, have been developed.

2. The most promising brazing alloy, containing 0.25Be, 0.49Si, 44.3Ni, 54.96Pd, has a melting temperature range of 2040 to 2120° F, is workable into thin strip stock, produces superior wetting of titanium and/or aluminum bearing high-temperature alloys, causes little base-metal penetration or erosion during brazing of thin-walled, wrought materials, has adequate shear strength to 1500° F and exhibits room-temperature ductility in brazed joints of various base metals.

3. The beryllium and/or silicon contents of the developed brazing alloys produce, in the presence of Pd and Ni, lower melting compositions during reactions with base metals AISI 304 and AISI 316 which enable brazing of these materials, with little base-metal grain coarsening or erosion, at temperatures of 1920 to 1985° F.

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Techniques for Welding Al-Mg Alloys

Report indicates that high-quality reproducible welds can be obtained by utilizing properly cleaned materials, optimum welding conditions and adequate tools and fixtures

BY DANIEL M. DALEY, JR.

ABSTRACT. Missile fabrication, such as seen in the Army's Redstone and Jupiter, requires a maximum weld quality and weld-joint efficiency. To obtain this, great care must be taken to utilize: (1) properly cleaned materials, (2) optimum welding conditions and (3) adequate tools and fixtures. It is the purpose of this report to show that by controlling these three items, superior quality fusion welds can be made with the aluminum-magnesium alloys.

Introduction

Missiles, such as the Army's Redstone and Jupiter, are essentially highly complex projectiles. In their simplest form, they consist of fuel tanks with a nose cone, a body and an engine. In addition, they have a guidance system for directing the missile to a given objective.

Missiles must be light in weight, easily fabricated and structurally rigid. In the Army's missile-development program, aluminum with a specific density of 2.7 g per cubic centimeter and a modulus of elasticity of 10.6 million was selected because it is a light material that is weldable in most of its alloy compositions. The reason for the weldability requirement is that the tanks must be pressure tight. Sealants for riveted construction are not compatible with oxidizing agents. Most of the weld fabrication is done in the center section or tank portion of the missile.

In the missiles developed at the Army Ballistic Missile Agency, the aluminum-magnesium alloys of the strain-hardening type were selected. These alloys were selected because their mechanical properties are less affected by the heating cycle of welding than some of the heat-treatable alloys and because ductility in the as-welded joint is more easily obtained.

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Scope of Investigation

Missile fabrication requires a maximum weld quality and weld joint efficiency. It is the objective of this report to show that by utilizing: (1) properly cleaned materials, (2) optimum welding conditions and (3) adequate tools and fixtures, it is possible to obtain high-quality, reproducible welds. The data presented will show the effects of some of these variables on weld quality in the aluminum-magnesium alloys. Evaluation of the welds is based upon their mechanical properties as well as X-ray inspection. The data included in this report on tooling are a minimum and do not include all of the tooling variables that can affect aluminum welds.

Materials Used

During this investigation, three of the aluminum-magnesium alloys were used. They were the 5052-H32, 5086-H34 and 5456-H24 aluminum alloys. Type 5356 filler wire was used for all weldments. The chemical analysis for these materials is shown in Table 1. Typical properties of the base metal and as-welded test panels are shown in Fig. 1. The 5052-H32 aluminum alloy was the material originally selected for missiles developed at the Army Ballistic Missile Agency. Through alloy-development programs, the 5086-H34 alloy became available and is the material currently used for the tank section on Jupiter missiles. The 5456-H24 alloy is the latest development in the Al-Mg type compositions and, because of its superior properties, will undoubtedly be used in some of the future missiles.

Because the 5086-H34 alloy is the alloy currently used in Jupiter missiles, most of the data obtained for this report were from weld panels prepared in this alloy.

Properly Cleaned Material

It has been found essential that the material in the area of the weld joint be adequately cleaned in order to obtain consistently high-quality, reproducible welds in the aluminum-

Table 1—Chemical Composition Range, %, Aluminum-magnesium Alloys

Element	5052-H32	5086-H34	5456-H24	5356 wire
Si	0.45	0.40	0.40	0.50
Fe		0.50		
Cu	0.10	0.10	0.05–0.20	0.10
Mn	0.10	0.20–0.7	0.5 –1.0	0.05–0.20
Mg	2.2 –2.8	3.5 –4.5	4.7 –5.5	4.5 –5.6
Cr	0.15–0.35	0.05–0.25	0.05–0.20	0.05–0.20
Zn	0.10	0.25	0.25	0.10
Ti	....	0.15	0.10	....
Be	....	....	0.0005	....
Other	0.15	0.15	0.15	0.15

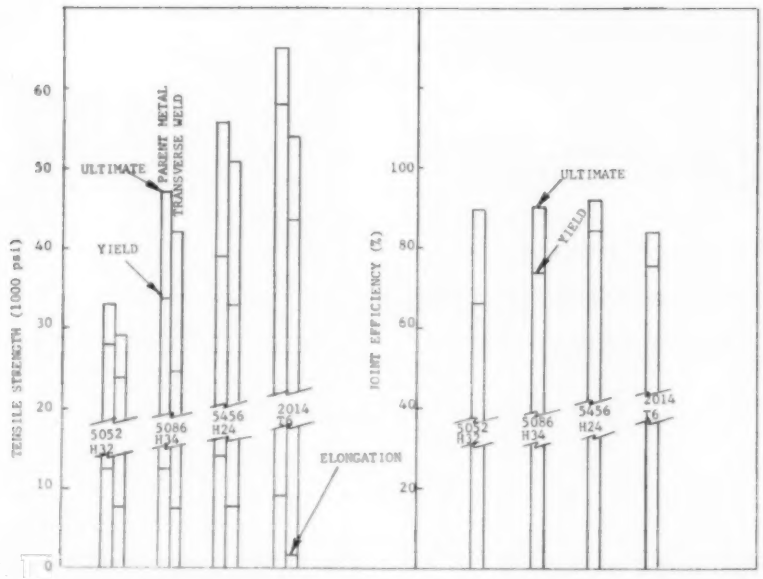


Fig. 1—Mechanical properties of aluminum alloys considered for welded-missile structures

magnesium alloys. To illustrate this fact, welds were prepared using the following cleaning procedures:

(*a*) Material was in the as-received condition with the weld joint edges left as-sheared.

(*b*) Material was in the as-received condition with the weld joint edges mechanically cleaned by draw filing.

(*c*) Material was chemically cleaned* with the weld the weld joint edges left as-sheared.

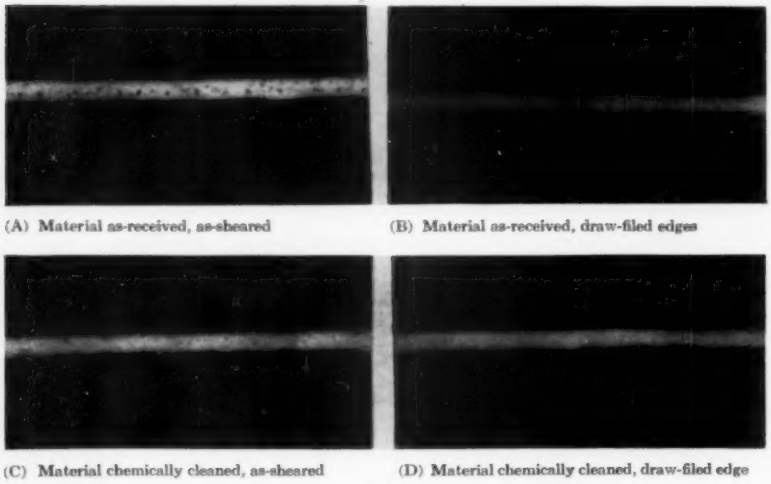
(*d*) Material was chemically cleaned and the weld joint edges mechanically cleaned by draw filing, giving a maximum condition of cleanliness.

Figure 2 shows the X-ray quality obtained for these four conditions of weld-joint cleaning. For the worst condition (*A* in Fig. 2), the weld contained the most porosity and is considered a Class V weld according to ABMA Standards. For condition *D*, the best condition of cleanliness, the weld was a Class I. Figure 3 shows the X-ray standards that were developed at ABMA for fusion welds in aluminum alloys. Class I denotes a defect-free weld while Class V denotes very poor-quality welds. These standards are used in the inspection of all fusion welds made on Jupiter missiles. Class II is the minimum for acceptable levels of porosity.

To illustrate the effect of X-ray quality on the mechanical properties of aluminum welds, test panels were prepared for each of the five classes of welds. The data obtained for these tests are shown in Fig. 4. These weld panels were made in 0.125-in. 5086-H34 material using 5356 filler wire and the consumable-electrode welding process. The damaging effect of high porosity on aluminum welds can be readily seen. Besides having lower average tensile properties, the Class V welds have a greater scattering of data than the Class I or II welds.

While it is necessary to have the best cleaning methods for properly preparing the material in the area of the weld joint, this alone will not insure the high-quality welds needed in missile structures. It has been found at ABMA that the quality of the alloy aluminum welding wire also has a direct bearing upon the

* Chemical cleaning consisted of using a vapor degrease, an alkaline cleaner, a cold-water rinse, a deoxidizer followed by a cold water rinse and air drying.



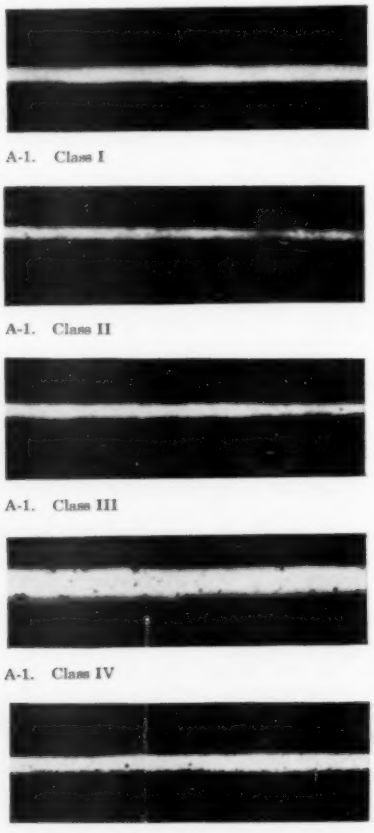
(A) Material as-received, as-sheared

(B) Material as-received, draw-filed edges

(C) Material chemically cleaned, as-sheared

(D) Material chemically cleaned, draw-filed edge

Fig. 2—Typical X-ray quality of welds having different cleaning procedures



A-1. Class I

A-1. Class II

A-1. Class III

A-1. Class IV

A-1. Class V

Fig. 3—ABMA X-ray standards

quality of welds. Therefore, in an effort to improve the weld soundness and reliability, a wire-evaluation test has been established. The purpose of this acceptance procedure was to obtain consistently the best wire available. This in turn has aided in the improvement of the quality of aluminum welds. The first requirement of acceptable wire is that its chemical composition be within the specification limits. Each reel of wire must meet a visual inspection. It must have a smooth, uniform finish and be free from kinks, scratches or other mechanical defects that might cause welding difficulties. The wire must be level-wound on reels so that it will feed in a smooth uniform manner. Figure 5 shows cross sections of good and poor welding wire. Defects such as shown can cause uneven wire feed that might result in poor weld quality. Once the welding wire passes visual inspection, three fillet welds are prepared in a special fixture designed for wire testing. Figure 6 shows the wire-test station used at ABMA. Welding conditions for the wire testing is established using a reference reel of welding wire that is known to produce quality welds under adverse conditions. X-ray examination is then made of the test weldments and compared against standards. For a given reel of aluminum welding wire to be considered acceptable for missile use, the center portion (Fig. 7) of three must pass X-ray examination. After the wire has satisfactorily passed these tests, it is repackaged and stored in an oven which is maintained at 110° F to prevent moisture pickup. The wire remains in the oven until it is needed for welding in the production shops.

Welding Conditions

Of equal importance to clean materials in missile fabrication is control over welding conditions. When possible, fully automatic welding equipment is used. This enables a more positive control over the welding current, voltage and other variables that might have an effect on the quality of the welds. In production welds on Jupiter missiles, tight control is maintained over welding conditions. Table 2 shows typical machine settings used at the Army Ballistic Missile Agency. They are a guide in establishing the exact settings to be used for a given fusion weld. Prior to making a production weld, a test panel is prepared and evaluated. The test panel must have a minimum ultimate joint efficiency of 80% of the base metal and be almost completely

Table 2—Typical Machine Settings for Welding Aluminum-magnesium Alloys

	0.090 in.	0.125 in.
Gas tungsten-arc process		
Voltage, v	13	13
Current, amp	180	210
Travel speed, ipm	36	36
Shielding, argon cfh	70	70
Gas metal-arc process		
Voltage, v	21	21
Current, amp	190	220
Travel speed, ipm	40	38
Shielding, argon cfh	90	90

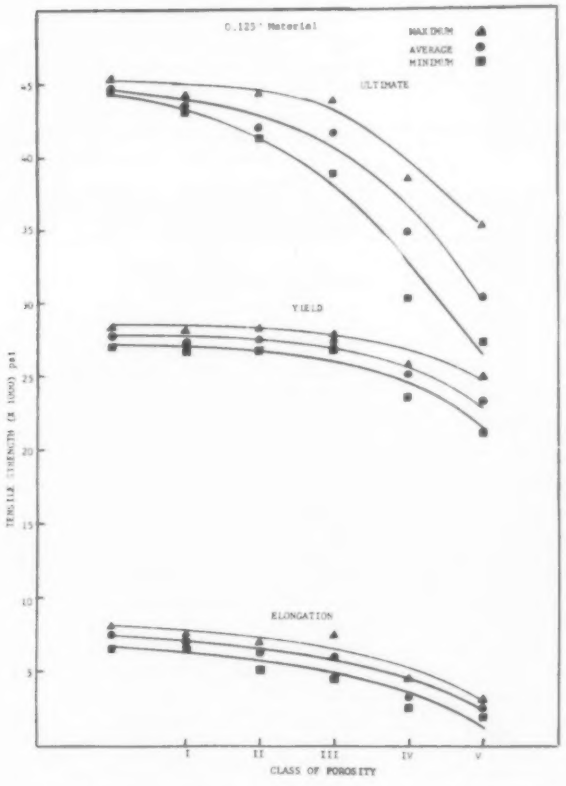


Fig. 4—Effect of porosity on aluminum welds 5086-H34 made with 5356 filler

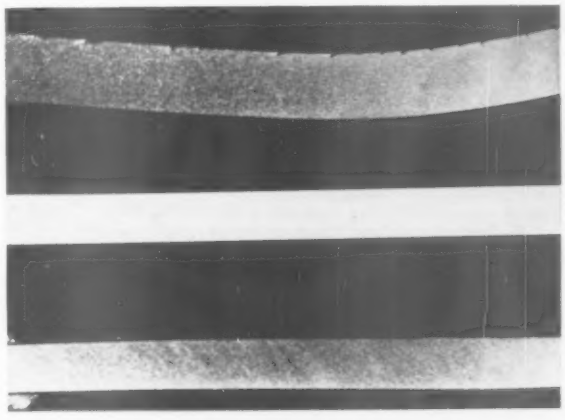


Fig. 5—Examples of good and poor aluminum welding wire

Fig. 6—Wire test station at ABMA

Fig. 7—Fillet-test weldments

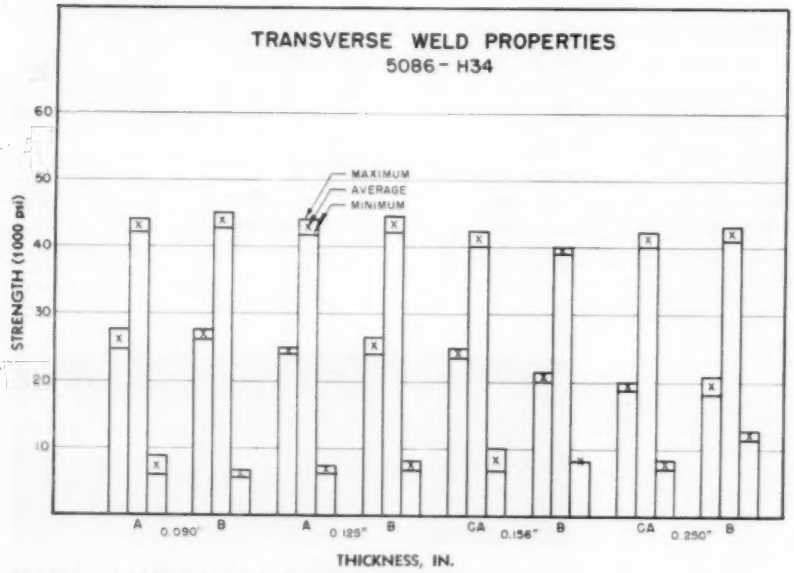


Fig. 8—Properties of gas tungsten-arc (A) and gas metal-arc (B) weldments in 5086-H34 aluminum alloy

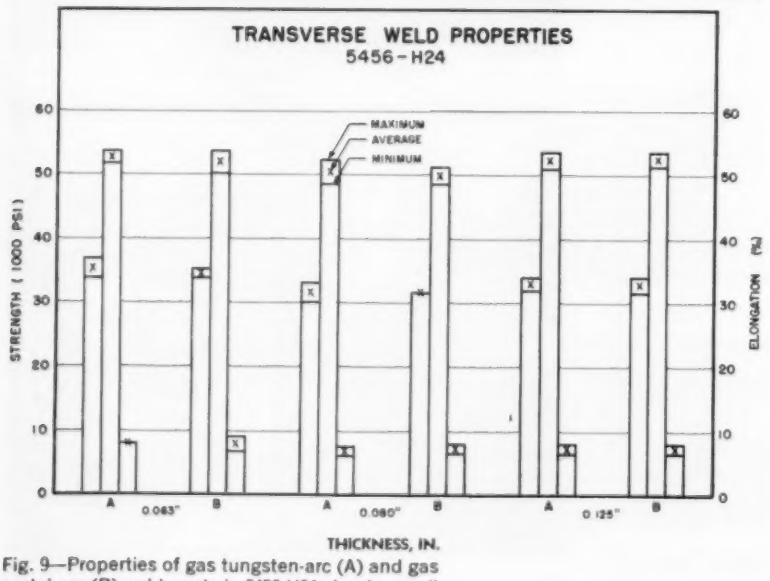


Fig. 9—Properties of gas tungsten-arc (A) and gas metal-arc (B) weldments in 5456-H34 aluminum alloy

free from porosity. Machine settings are adjusted until acceptable test panels are made. The production weld is made with the same settings used in preparing the acceptable test panel. This procedure is used for each production weld made. This is considered one of the reasons for the consistent high quality of the welds made in Jupiter missiles.

Both the gas tungsten-arc and the consumable-electrode or gas metal-arc welding processes are used for fusion welding in missiles. The gas tungsten-arc process is preferred for the thinner sheet material because there is more control over the welding arc and therefore less chance for burn-through. In the fusion welding of the heavier thickness of aluminum sheet material, the gas metal-arc process is usually preferred because penetration is more easily and consistently obtained. Figures 8 and 9 respectively, illustrate the mechanical properties obtained for both gas tungsten-arc and metal-arc weld panels using 5086-H34 and 5456-H24 aluminum alloys over a range of thicknesses. The data presented are typical of properties that can be obtained. It can be seen from this data that the gas tungsten-arc welds have slightly better properties than the gas metal-arc welds in the thicknesses tested.

At the Army Ballistic Missile Agency, the gas tungsten-arc process is used for the longitudinal welds because there is a better fit-up of the weld joint and uniform penetration is assured. For the circumferential welds where it is difficult to get rigid clamping and uniform fit-up, the gas metal-arc process is used to assure quality welds.

Missile Tooling

In addition to controlling the cleanliness of the materials and the welding conditions, tooling has been found to be an important factor in obtaining the high quality, reproducible welds needed for missile structures. Without proper support, proper fit-up and proper hold-down pressure, poor weld efficiency and weld quality can result. For example, if the weld fit-up is not adequate, the resulting weld may have lower mechanical properties than required for a given structure. Figure 10 illustrates the effect of a poor fit-up of the weld joint. For only a misfit of 0.020 in. there is an appreciable loss of strength. From these data it can be easily seen that it is important to have as good a fit-up of the weld joint as possible and this can be done only through adequate missile tooling.

In order to improve missile tooling, studies have been conducted to evaluate some of the tooling conditions that might have an effect on the properties of missile weldments.†

Figure 11 illustrates the effect of the mass of the backing bar on the properties of 5086-H34 aluminum alloy using the gas tungsten-arc welding process with 0.090-in. sheet material. The data presented indicate that when using a 1- x 3-in. copper backing bar, the as-welded tensile properties will be better than when using a smaller size copper backing bar. Also, it can be seen that the weld panels made using a stainless-steel backing bar have lower mechanical properties than the weld panels made using a copper backing bar. In summarizing, the data of Fig. 11 indicate that a large copper backing bar should be used when welding Al-Mg alloys by means of the gas tungsten-arc welding process.

Another variable of missile tooling that has been investigated is the geometry of the groove in the backing bar. Table 3 presents the data obtained for the 5456-H24 aluminum alloy for both 0.090- and 0.125-in. material using both a rectangular and a radius grooved backing bar. The weld test panels were prepared using the tungsten-arc welding process. In the thicknesses investigated, the rectangular-grooved backing bar produced weld-test panels having slightly better as-welded mechanical properties than the welds made using a radius-grooved backing bar. For gas metal-arc welding, it has been found that a radius-grooved backing bar produces the maximum as-welded properties in the Al-Mg alloys.

† The tooling studies reported in this paper are related chiefly to the backing bar and are only a few of the tooling variables that can have an effect on the weld properties in missile structures. It is hoped that these and other studies that are in progress will aid in the future design of tools and fixtures used for missile welding.

Table 3—Mechanical Properties of 5456-H24 Aluminum Welded Using the Tungsten-arc Process

	Radius groove			Rectangular groove		
	Yield strength, psi	Ultimate strength, psi	Elongation, %	Yield strength, psi	Ultimate strength, psi	Elongation, %
0.090 in.						
Min.	32,800	50,300	5.5	35,200	54,000	7.0
Max.	35,600	54,400	7.5	36,200	56,700	8.0
Avg.	34,300	52,300	6.5	35,800	55,600	7.6
0.125 in.						
Min.	31,300	51,900	6.5	32,700	51,600	7.0
Max.	33,600	54,000	8.0	34,200	54,700	8.0
Avg.	32,800	52,800	7.2	33,000	53,300	7.6

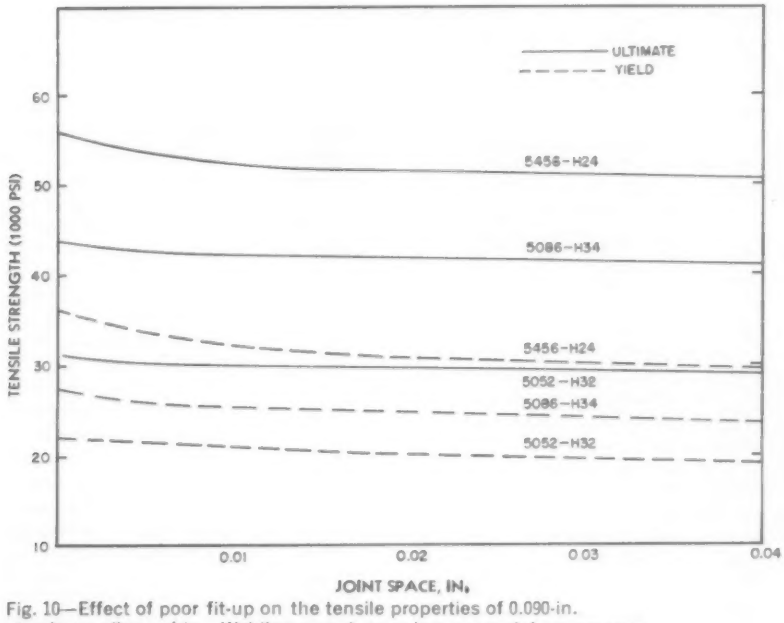


Fig. 10—Effect of poor fit-up on the tensile properties of 0.090-in. aluminum-alloy welds. Welding was done using gas metal-arc process

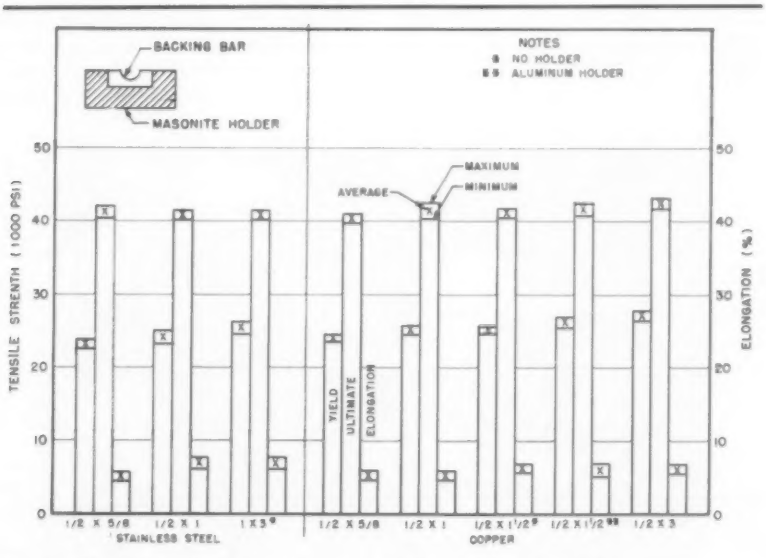


Fig. 11—Effect of backing-bar size and material on tensile properties of Al-Mg weldments

Conclusions

Based upon the data obtained, it is concluded that to consistently obtain high-quality, reproducible welds needed for missile applications utilizing the aluminum-magnesium alloys, it is necessary to maintain close control over the materials used, the welding conditions and the tooling utilized. It is considered essential that only properly cleaned materials, optimum welding conditions and adequate tooling be used in the fusion welding of missile structures.

Interpretive commentary on the application of theory to experimental results for

Stresses and Deflections Due to Local Loadings on Cylindrical Shells

BY P. P. BIJLAARD AND E. T. CRANCH

SUMMARY. The PVRC Design Division has, through its Subcommittee on External Loadings on Pressure Vessels and through financial assistance from the U. S. Navy Bureau of Ships, sponsored an extensive research program at Cornell University with the objective of providing designers with the very much needed information to compute stresses in cylindrical and spherical shells due to loadings which impose localized radial forces or longitudinal or circumferential moments. The resulting theoretical developments have already been published in a series of papers and PVRC Bulletins by P. P. Bijlaard.

Checks against available published experimental data indicated reasonable agreement but such data are extremely limited. Accordingly, the program at Cornell was expanded to include tests of such loadings on a cylindrical shell and also on spherical shells to provide additional data for spot-checking the theory.

Figure 1 shows the cylindrical shell under test. The shell is 48-in. ID by $^{5}/_{8}$-in thick. Five attachments were tested under radial force, longitudinal and circumferential moment loading with and without internal pressure in the vessel. The attachments consisted of a $3^{1}/_{2}$-in. diam bar, a 6-in. pipe welded to the shell (no hole), a 6-in. pipe welded into a hole (unreinforced nozzle type), a similar connection with reinforcing pad and a $3^{1}/_{2}$ x 14-in. rectangular attachment.

The experimental work is now complete. A detailed report by E. T. Cranch on the cylindrical shell tests is given in WRC Bulletin No. 60, May 1960.

A report on the spherical shell tests is in course of preparation. Bulletin No. 60 includes an interpretive commentary by Professors Bijlaard and Cranch which, because of its general interest, is given below. Designers interested in this problem should consult the full report.

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Introduction

The experimental investigation of stresses and deflections in the neighborhood of attachments to a cylindrical shell affords an opportunity to compare measured values with theoretical calculations.[1] The experimental report contains such a comparison together with a detailed discussion of the effect of different types of loads on several attachments. This interpretive commentary is intended to emphasize some of the major conclusions and cases where agreement or disagreement occurs between theory and experiment. An examination of the experimental report indicates that theory and experiment agree quite well and this gives confidence to the use of the theory to problems of this type.

Radial Load

The largest stress on the shell occurs in the circumferential direction at the edge of the attachment on the circumferential centerline. The experimental results for this stress component are somewhat higher than theory; however, the experimental values are the result of an extrapolation to the edge of the attachment. If the experimental values are based on an extrapolation to the edge of the weld and the theory is based on an attachment dimension including the weld thickness, then it can be shown that agreement between the two is satisfactory. The experimental values indicate that attachment rigidity and resulting eccentricity cause the increase of experiment over theory. The effect of eccentricity for radial loading is discussed in connection with Fig. 2 under the section on circumferential couple loading. It should also be kept in mind that the gages closest to the attachments were at a distance from the edge of the weld of about 0.3 times the shell thickness. The stress distribution is not linear close to the re-entrant corner so that measured bending and membrane

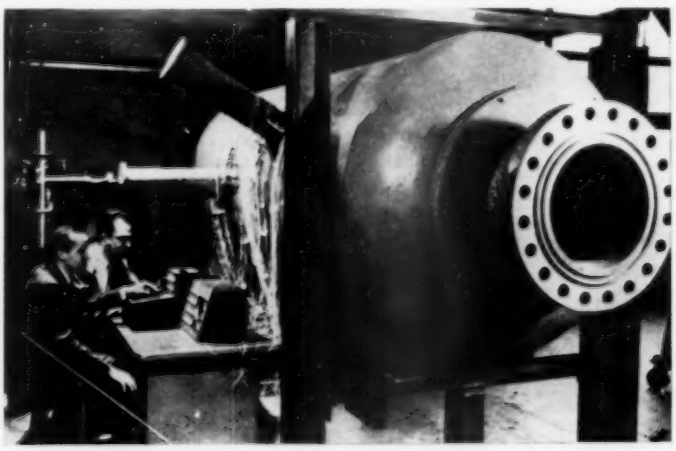

Fig. 1—Pressure vessel under external loading tests at Cornell University

stresses are higher than those computed under the assumption of linear stress distribution. In this connection, it was suggested in WRC Bulletin 50, page 8, to use a stress concentration factor in case of fatigue loading.

The rectangular attachment with side ratio 4:1 showed that the stress is largest in the corner regions and is appreciably below theoretical predictions on the circumferential centerline. In general, such rectangular shapes should be avoided or rounded off but, if used, one cannot expect a theory based on uniform load distribution to give highly accurate results.

The constraining effect of attachment rigidity is very evident in the longitudinal stresses along a circumferential centerline and the circumferential stresses along a longitudinal centerline. The theoretical values are obtained by shifting the stresses at the center of the loaded region to the edge of the attachment (or weld). As expected, experiment shows that the attachment rigidity constrains the development of stresses in a direction tangent to the edge of the attachment. Although these stress components are not usually governing, their magnitude is best determined from the theoretical curves by finding the magnitude at the point in question from the unshifted curves.

The two attachments most closely representing a practical installation were a 6-in. pipe piercing the wall of the shell and a similar pipe with a reinforcing pad. In both of these installations, the *largest measured stresses occurred on the attachment pipe* where it joined the shell on the circumferential centerline. Thus, it is important not to neglect the stresses in the wall of the attachment for they can be governing in many cases and can necessitate thickening or the use of reinforcing on the attachment.

Experimental and theoretical deflection values show that the deflection is sensitive to detailed conditions at the attachment. Some of the experimental values are not highly accurate due to inherent experimental difficulties; however, the experimental and theoretical values are of the same order of magnitude. When shell continuity is destroyed by cutting a hole to insert a pipe, the deflection is increased considerably over the theoretical prediction based upon a continuous shell.

Circumferential Couple

The experimental and theoretical values are in general agreement *except* for the circumferential membrane stresses and the circumferential bending stresses for the attachment with reinforcing pad.

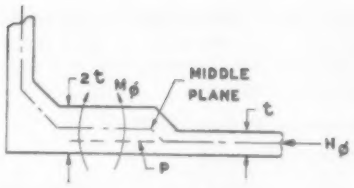

Fig. 2—Experimental attachment with reinforcing pad

The rigidity of the attachments causes the actual load distribution on the shell to be different from that assumed in theory. A local region of high load occurs on the circumferential centerline and results in circumferential membrane forces two to four times the theoretical results. This effect must be taken into account when using the theoretical design curves.

The high circumferential bending and membrane stresses for the attachment with reinforcing pad are also affected by the eccentricity caused by the one-sided pad. As shown in Fig. 2, page 66 of WRC Bulletin 49, the theory on which the design recommendations are based assumes a pad such that the middle plane coincides with the middle plane of the shell. In the experimental attachment, as shown in Fig. 2, the pad is placed on the outside of the cylinder, thus giving rise to eccentricity. This has the following effects:

The bending moment M_ϕ in the pad causes tensile stresses that tend to expand the fibers in a plane P coinciding with the middle plane of the shell outside the pad. This expansion is resisted by the shell outside the pad and contributes to the increased membrane stresses observed experimentally. Further, the offset of $t/2$ of the middle planes of pad and shell at the weld causes extra positive bending moments M_ϕ in the shell outside the pad. Assuming the membrane force N_ϕ at the toe of the weld to act along a plane halfway between the middle planes of pad and shell, its moment arm is $t/4$ and gives an extra bending moment at the toe of $(t/4)\ N_\phi$. The experimentally determined circumferential membrane stress at the toe is $\sigma_\phi = 0.091M$ which gives the extra bending moment $M_\phi = (t\sigma_\phi)t/4 = 0.091M\ t^2/4$ and the extra bending stress $\sigma_\phi = 6M_\phi/t^2 = 0.136M$. This must be added to the theoretically determined bending stress $\sigma_\phi = 0.29M$ for a concentric pad and results in a bending stress of $0.426M$, in good agreement with the experimental value of $0.41M$. The calculation can also be made assuming the pad plus weld as the attachment dimension and assuming $\gamma = a/t_p$, where t_p is the total thickness of the pad as recommended in Bulletin 50. By taking the membrane stress to be three times the theoretical value, the extra bending stress is $0.16M$. If this is added to the theoretical bending stress, $\sigma_\phi = 0.25M$, computed without the 20% increase recommended for concentric pads, the total circumferential bending stress is $\sigma_\phi = 0.41M$ in exact agreement with experiment. This same effect of eccentricity, but to a smaller degree, is present in other attachments due to the eccentrically situated fillet welds. Further, the above described action is also present to a lesser extent under radial load. For a case with eccentric reinforcing pad, for radial load, good agreement with experiment is obtained if one assumes membrane stresses equal to the theoretical value N_ϕ for a concentric pad and if one adds an extra moment of $N_\phi(t/4)$ to the theoretical bending moments M_ϕ.

The general agreement of experiment and theory indicates that the dimensional correction factor of 0.85 introduced in the theoretical calculations (see Reference 3) is necessary. Its physical basis lies in the fact that the actual circular loading area is smaller than that of the circumscribed square and that in all experimental tests reported, the rigidity of the attachments causes a localized increase of transmitted loads such that the theoretical distribution is not present. This increase is compensated for theoretically by reducing the attachment dimensions by a 0.85 factor which results in increased theoretical values.

A comparison of results for the 6-in. pipe and the 6-in. pipe with reinforcing pad reveals that, for this type of loading and pad design, the maximum stress on the shell is essentially the same in the two cases. Thus, the eccentric pad is ineffective in reducing the maximum stress.

The maximum stress *in the shell* occurs in the circumferential direction on the circumferential centerline. However, as in the radial load tests, the *maximum stress occurs on the wall of the attachment pipe* in the case of the 6-in. pipe and 6-in. pipe with pad.

The experimental rotations were consistently less than the theoretical

values by about 25%. This is due to the fact that the theory assumes a continuous shell which bends under the distributed load; however, the attachment rigidity constrains the bending of the shell wall and results in reduced deflections and rotations.

Longitudinal Couple

The experimental and theoretical results are in very good agreement and again substantiate the use of the 0.85 dimensional correction factor discussed under circumferential couple loading. The eccentricity effect explained under circumferential couple loading is not important in the longitudinal couple case because the shell curvature makes the longitudinal stiffness greater than the circumferential stiffness. Thus, the eccentricity effect cannot be estimated in the same way as before and it is not a major effect in the longitudinal direction.

Again, the maximum measured stresses for the 6-in. pipe and pipe plus pad occur on the attachment pipe at the attachment-shell joint on the longitudinal centerline. The reinforcing pad is effective in reducing the maximum stress in the shell under longitudinal couple loading.

The theoretical and experimental rotations are in excellent agreement. The practical absence of the influence of the attachment rigidity is due to the fact that in this case the bending of the continuous shell under the distributed load, as assumed in the theory, is much smaller than in the case of a circumferential couple, since the shell is much more rigid against bending by a longitudinal couple.

Internal Pressure Plus External Loads

Experiments were performed when the cylinder was under internal pressure alone and when the three types of external loads were added to the pressurized cylinder.

The results of the tests with just internal pressure indicate that appreciable membrane and bending stresses are induced by the attachments. No theory exists for determining these stresses but their magnitude indicates that it is essential to have knowledge or an estimate of their magnitude. The presence of a hole or attachment causes a stress concentration which depends on the rigidity of the attachment. The test results show membrane stresses falling between the stress concentrations at a hole and a rigid plug in a flat plate. Appreciable bending is induced by attachment eccentricity which results in the membrane stresses creating bending action as described under circumferential couple loading.

All the combined loading tests (internal pressure plus external load) indicate that it is essential to know the stress concentration factors to be applied for the case of internal pressure alone. These are not known theoretically, but for the present cases they can be derived from the test results for internal pressure only. When these derived values are used, the experimental and theoretical results are in good agreement.

Previous theoretical work showed that the membrane and bending forces due to external loads are somewhat reduced when the shell is initially pressurized. This effect was verified experimentally.

In the case of combined radial loading and internal pressure, the maximum stress still occurred on the attachment pipe for the 6-in. pipe and 6-in. pipe plus pad. For combined circumferential moment and internal pressure loading, the maximum stress location shifted from the attachments to the shell. In the case of combined longitudinal moment and internal pressure loading, the maximum stress for the 6-in. pipe attachment was on the shell while for the pad the maximum stress was on the attachment pipe. This again emphasizes the importance of the fact that the maximum stress can occur on the attachment and that the location can shift under combined loading.

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WRC Bulletin No. 59

"Factors Which Affect Low-alloy Weld-metal Notch Toughness"

Welding Research Council Bulletin No. 59, published in April 1960, concerns a study of a large number of commercial and experimental electrodes welded under various conditions which has revealed the influence of weld metal analysis, tensile strength, electrode size, coating design, stress relief heat treatments, preheat, welding position, dilution and restraint on the Charpy V-notch properties. Welding procedures are suggested which favor the highest possible notch toughness. This is a very comprehensive treatment of the subject by Stanley S. Sagan and Hallock C. Campbell of the Research Department of the Arcos Corp.

The price of this Bulletin is $1.00 and single copies may be purchased through the AMERICAN WELDING SOCIETY, 33 W. 39th St., New York 18, N. Y. Quantity lots may be purchased through the Welding Research Council, 29 W. 39th St., New York 18, N. Y.

Explosion-Bulge Tests of Armor Weldments

Results of investigation indicate that the explosion-bulge test is useful for determining the toughness performance of Army Ordnance armor weldments, provided extreme care s used in interpreting the test results

BY S. M. SILVERSTEIN, R. P. SOPHER AND P. J. RIEPPEL

ABSTRACT. The object of this investigation was to determine whether the explosion-bulge test could be useful for determining the toughness performance of weldments in Army Ordnance high-strength steel (armor). A study was made of ferritic Grades 260, 230 and 180 electrodes as well as austenitic Type 307 electrodes deposited in butt joints in a single heat of 1-in. Army Ordnance armor plate. Specimens were explosion tested over a range of temperatures to determine the ductile-to-brittle performance temperature range of the weldments.

The explosion-bulge tests were evaluated on the basis of reduction in plate thickness prior to failure and the amount of shear on the fracture face. Reduction in plate thickness was taken to be a measure of the resistance of the weldments to crack initiation. The amount of shear was considered to be a measure of the resistance of the weldments to fracture propagation. There was little difference in the performances of the weldments made with the high-strength ferritic and the austenitic electrodes; however, the weldments prepared with the Grade 180 electrodes were definitely inferior to the other weldments. The explosion-bulge test rated armor weldments made with the four electrodes in the same general order as they are rated by H-plate tests.

The results of this investigation indicate that the explosion-bulge test is useful for determining the toughness performance of Army Ordnance armor weldments, provided extreme care is used in interpreting the test results. Further work with this test is recommended.

Introduction

The H-plate test has been a standard test for evaluating the toughness performance of welded joints in Ordnance armor since the early part of World War II. There have been many attempts to find a less expensive substitute for the H-plate, but generally it has been the only test considered satisfactory for evaluating the ballistic properties of armor weldments. This investigation was undertaken to determine whether the explosion bulge test plate could be used as a substitute for the H-plate in evaluating the shock performance of armor weldments. Four series of bulge plates in 1-in. Army Ordnance armor were welded with ferritic Grades 260, 230 and 180 electrodes and austenitic Type 307 electrodes. These plates were tested over a range of temperatures from 215 to −100° F. Results or ratings of the bulge-plate weldments were compared with ratings of four series of H-plate weldments studied in a previous investigation.[1] The H-plates were made from the same lot of armor and welded with the same four grades of electrodes as were used for the bulge-plate study. Thus, information from the previous investigation with H-plates became a basis for evaluating information obtained from the explosion-bulge tests.

In the previous investigation, as noted above, a series of H-plates made with each of four classes of electrodes was tested over a temperature range from 70 to −65° F. This series of H-plate tests rated the armor weldments made by the various electrodes in the following descending order: ferritic Grade 230, austenitic Type 307, ferritic Grade 260 and ferritic Grade 180. The criterion for this rating was inches of cracking, which is believed to be a measure of the H-plate's resistance to crack propagation. This previous study, along with other work,[2] showed that a series of H-plates must be tested over a range of temperatures to obtain a complete evaluation of armor weldments made with a given electrode or welding procedure. The minimum testing temperature for H-plates should include the lowest anticipated service temperature. In standard H-plate testing, it has not been a practice to test over a range of temperatures. Standard H-plate qualification procedures specify that 6 in. is the maximum allowable plate cracking for the test to be considered a "fair test." When a series of specimens is tested over a range of temperatures, much valuable information for evaluating and comparing weldments is lost when specimens having more than 6 in. of cracking are not considered a "fair test." Therefore, it is believed that the concept of the "fair test" should be revised and that a series of H-plates always should be used when evaluating the ballistic performance of weldments made with the different electrodes.

Needless to say, if a series of H-plates is used to obtain a good evaluation of weldment instead of a single H-plate, the time and cost involved in this type of testing are extensive. A less expensive and less time-consuming test is, therefore, very desirable. The explosion-bulge test was tried to determine whether it would fill this need.

The explosion-bulge test[3,4] has been used quite successfully for evaluating the shock-impact performance of Navy armor and ship steels, as well as weldments in these steels. In the explosion-bulge test, the specimens are placed on a circular die plate and are deformed into the die by means of an explosive shock. An area of uniform

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Table 1—Mechanical Properties and Chemical Composition of Armor Plate and Weld Metals

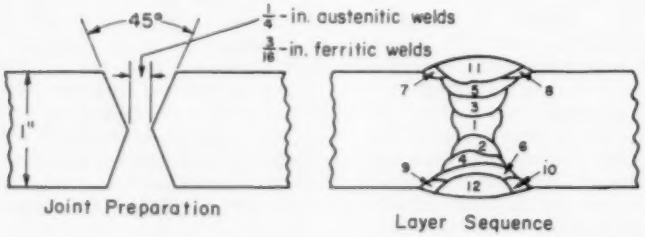
Material	Yield tensile strength,[a] 1000 psi	Ultimate tensile strength,[a] 1000 psi	Elongation, %	Reduction in area,[a] %	V-notch Charpy bar, ft-lb 78° F	0° F	−40°F	−65°F	Composition, %[a] C	Mn	Si	Ni	Cr	Mo	V
Armor plate	157	168	10[b]	..	..	..	..	..	0.25	1.58	0.16	...	...	0.45	0.01
Grade 260 weld metal	107	118	19[c]	52	47	26	17	12	0.07	0.75	0.33	1.75	...	0.80	0.20
Grade 180 weld metal	70	76	33[c]	67	45	12	6	4	0.10	0.70	0.35	...	...	...	...
Type 307 weld metal	66	90	44[c]	..	63	54	47	42	0.09	3.78	0.64	9.66	20.22	1.40	...
Grade 230 weld metal	91	102	24[c]	64	70	50	38	23	0.07	0.74	0.41	1.72	...	0.29	0.13

[a] Manufacturer's strength data and chemical composition given for commercial electrodes (all-weld-metal specimens).
[b] In 8-in. gage length.
[c] In 2-in. gage length.

biaxial loading is produced in the center of the pole area of the bulge. Thus, in bulging a weldment, the weld metal, heat-affected zone and adjacent base metal are subjected to essentially uniform biaxial loading in the pole area. The loading and deformation pattern is not exactly like that produced by a projectile striking armor, but it was believed possible that the bulge plate might rate the weldments in the same order as the ballistic H-plate. The cost and time advantage of the bulge plate was attractive enough to warrant the investigation.

Preparation and Testing of Explosion-bulge Plates

Four groups of bulge specimens, 15 plates in each, were welded with austenitic Type 307 and ferritic Grades 260, 230 and 180 electrodes. The mechanical properties and chemical compositions of the Army Ordnance armor and weld deposits made with these electrodes are listed in Table I. The austenitic electrode was chosen because it is used most commonly for welding armored vehicles. The Grades 260 and 230 electrodes were chosen because of the interest in substituting these electrodes for the austenitic type. Although the Grade 180 is known to have poor toughness properties, it was included in the study to observe whether the test was capable of showing a difference in the toughness performance of weldments, as was already demonstrated by the H-plate.[1,5]



Electrode Classification	Pass	Amperes	Arc Volts	Electrode Size, inch	Preheat and Interpass Temperature, °F
Grade 260	1-6, 11, 12 7-10	200 150	24 24	3/16 5/32	190 to 210 all passes
Grade 180	1-6, 11, 12 7-10	190 140	24 24	3/16 5/32	
Austenitic Type 307	1-6, 11, 12 7-10	170 130	23 22	3/16 5/32	
Grade 230	1-6, 11, 12 7-10	190 140	24 24	3/16 5/32	

Fig. 1—Details of weld joint of explosion-bulge specimen showing joint preparation, electrode welding conditions and layer sequence

Preparation of Specimens

All of the bulge specimens were fabricated from the same mill heat of armor. The pass sequence, joint preparation and welding conditions for all types of electrodes used are shown in Fig. 1. After the root pass was deposited, the direction of welding was altered for each subsequent pass. Prior to use, the covered electrodes were baked from 4 to 6 hr. The austenitic Type 307 electrode was baked at 400° F, while the ferritic electrodes were baked at 900° F. During use in the laboratory, the electrodes were stored in a desiccator to reduce any pickup of moisture by the coverings.

A fixture was fabricated to prevent warpage during the welding of the bulge specimens. In preparing the specimens, two plates, 1 ft wide x 2 ft long, were beveled by oxygen cutting along the 2-ft length and welded together to give a double-vee butt joint 2 ft long. The specimens were aged in a water bath at 200° F for 48 hr immediately after welding to minimize the formation of microcracks on cooling. All welds were radiographed. Welds which did not pass the standards set forth in U. S. Army Specification 57-0-8 were ground out, repaired, aged again and reradiographed.

The weld reinforcement was ground off on one face of the specimen for a distance of $4^1/_2$ in. from each end to allow good contact around the circumference of the die. The mill scale was ground off both sides of the specimen around the pole (central) area. The weld was left in the as-deposited condition. A wash primer paint with dye pigments was used to color code this area on the tension side of the specimen, thus facilitating reassembly of the fractured plate for examination after testing. Uncolored wash primer paint was used on the other side of the specimen; both coats of paint helped prevent oxidation of the prepared surfaces. Dots, $^1/_4$ in. in diam, were painted at 1, $1^1/_2$ and 2 in. from the center line of the weld at the center of the plate and along a line perpendicular to the welded joint. These spots served as reference marks for measuring the thickness of the specimens before and after testing.

Testing Procedure

All of the explosion-bulge tests described in this paper were conducted at the Aberdeen Proving Ground.

Work with the explosion-bulge on ship steels was done with a 20 x 20-in. die plate having a 12-in. diam. circular opening.[3] A 24 x 24-in. die plate with a 16-in. circular hole was prepared for the armor-plate weldment tests. This larger diameter die would permit more deformation of the weldment before failure and was selected because: (1) the armor plate studied in this work has approximately 10% elongation over an 8-in. gage length, compared with 25 to 30% for the shipgrade steels, and (2) the plate thickness of the armor was 1 in. while that of the ship steels was $^3/_4$ in.

These tests on armor were conducted with a 7-lb charge of Pentolite explosive at a standoff distance of 18 in. The specimens were tested over a range of temperatures from 215 to −100° F. Test specimens that did not fracture after the first charge were returned to the cold chamber, or reheated, in preparation for the next charge.

Test Results

In order to obtain data for determining the usefulness of the explosion test for evaluating armor weldments, the specimens were evaluated on the basis of reduction in plate thickness and amount of shear on the fracture face. The data are listed in Table 2.

Reduction in Plate Thickness

The reduction in thickness (strain) of a material prior to fracture initiation has been used to determine the comparative energy-absorption capacity of the material under test. Since this strain occurs prior to fracture initiation, it then may be considered as a measure of the resistance of the material to fracture initiation. Once a crack is initiated, the deformation is confined primarily to material at the crack front. In evaluating the test results of this study, all the test specimens were evaluated on the assumption that the reduction in plate thickness prior to fracture was not affected by the number of charges required to produce fracture.

The reduction in plate thickness was determined by measuring the thickness of the plate in the pole area before and after testing. The thickness measurements were taken on both sides of the welded joint at 1, $1^1/_2$ and 2 in. from the centerline of the weld. The values measured at the $1^1/_2$-in. distance were used in this study, because the scatter in the results obtained at this location was found to be the least for any given group of specimens. Care was taken in determining the reduction in thickness, because the maximum value was approximately $4^1/_2$ percent.

Table 2—Explosion-bulge Test Data

Electrode type	Plate number	Test temperature, ° F	Number of charges	Reduction in plate thickness, [a] %	Shear lip, [b] in.
Grade 260	UF24	120	3	4.05	—[c]
	UF31	85	3	2.88	11/64
	UF25	30	2	2.10	19/64
	UF26	0	3	3.85	12/64
	UF27	−20	2	2.40	13/64
	UF28	−40	3	3.26	10/64
	UF33	−40	3	2.85	13/64
	UF35	−40	1	1.50	10/64
	UF32	−60	3	2.79	8/64
	UF34	−60	2	1.55	6/64
	UF29	−80	1	1.46	1/64
	UF30	−100	1	0.60	2/64
Grade 230	UJ24	120	3	3.96	—[c]
	UJ31	80	3	2.85	19/64
	UJ34	80	3	3.00	—[c]
	UJ25	30	2	2.92	27/64
	UJ26	0	2	1.66	22/64
	UJ27	−20	1	1.53	26/64
	UJ28	−40	1	0.44	17/64
	UJ35	−40	1	1.37	17/64
	UJ23	−60	1	0.50	17/64
	UJ32	−60	1	0.61	20/64
	UJ33	−60	1	0.90	16/64
	UJ29	−80	1	0.97	11/64
	UJ30	−100	1	0.05	3/64
Grade 180	UG28	215	1	1.40	—[c]
	UG24	120	1	0.65	26/64
	UG25	30	1	0.11	19/64
	UG26	0	1	0.11	1/64
Type 307	UH34	215	4	2.65	—[c]
	UH24	120	2	2.60	—[c]
	UH25	25	2	2.20	23/64
	UH26	0	3	3.23	18/64
	UH27	−20	1	1.41	15/64
	UH28	−40	2	2.40	12/64
	UH33	−40	1	1.63	15/64
	UH23	−60	1	2.50	10/64
	UH32	−60	3	2.95	—[c]
	UH35	−60	1	1.60	23/64
	UH31	−60	1	1.25	14/64
	UH29	−80	1	1.07	16/64
	UH30	−100	1	0.15	0/64

[a] These measurements were taken on both sides of the weld joint $1^1/_2$ in. from the centerline of the weld.

[b] These measurements were taken on both sides of the fracture face at the center and 4 in. on either side of the test specimen.

[c] These measurements could not be obtained as a result of shattering or incomplete failure of the weldments.

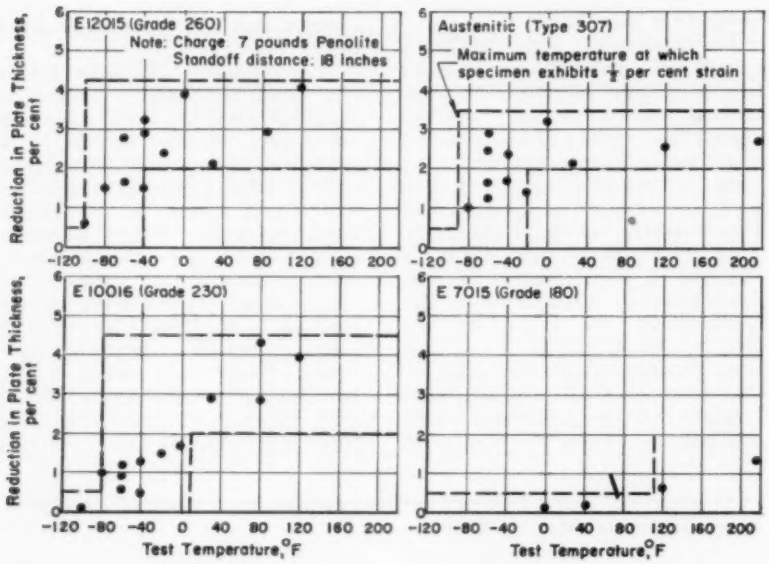

E12015 (Grade 260)
Note: Charge 7 pounds Penolite
Standoff distance: 18 inches
Austenitic (Type 307)
Maximum temperature at which specimen exhibits ½ per cent strain
E 10016 (Grade 230)
E 7015 (Grade 180)
Reduction in Plate Thickness, per cent
Test Temperature, °F

Fig. 2—Explosion-bulge-test results. Welds in 1-in. plate

When working with such small values, errors made in the thickness measurements result in a sizable error in the percent reduction values.

The results obtained from plotting the values of reduction in plate thickness vs. test temperature are shown in Fig. 2. These plots were made by arbitrarily using a ½% or less reduction in thickness as constituting a weldment of unsatisfactory ductility. Weldments exhibiting greater than ½% reduction in thickness were considered to possess some degree of ductility. On the basis of the temperature at which the weldments exhibit ½% reduction in thickness, the weldments were rated in the following descending order: Grade 260, −100° F; austenitic Type 307, −90° F; Grade 230, −80° F; and Grade 180, 110° F. For all practical purposes, this criterion shows that there is little difference among the test results of the first three groups of weldments.

The line at the lowest temperature at which the specimens exhibited more than ½% reduction in thickness was drawn by taking all data into consideration. It is possible that the location of this line might have changed if more specimens were tested in the low-temperature range. The ½% reduction in thickness temperature for the Grade 180 welded joints was approximately 110° F, as shown in Fig. 2. A transition range was not shown on the graph because the maximum reduction in plate thickness of the Grade 180 bulge plates was less than 2% at 215° F test temperature.

By considering the transition range (½ to 2% reduction in plate thickness) which includes the temperature where the fracture changes from a cleavage to a shear type, the weldments made with the Grade 260 (E12015) and Type 307 electrodes showed similar performances. These two groups of weldments showed greater reduction in plate thickness in the transition range prior to fracture than the Grade 230 (E10016) weldments. The scatter in the test results of the Grade 230 (E10016) specimens was quite small in the transition range. There was more scatter in the test results of the other groups of specimens; however, examination of the fracture surfaces did not reveal any defects which might cause this scatter.

Depth of bulge also was considered as a method of rating the welded joints. However, depth of bulge is related to reduction in thickness, i.e., as the depth of bulge increases, the base material is reduced in thickness. In addition, the depth of bulge was difficult to measure for these tests since, at low temperature, extreme cracking occurred in the specimens. Figures 3 through 6 illustrate the decreasing depth of bulge of the test plates with decreasing test temperature.

Degree of Shear

An examination of the fractures indicated that the amount of shear of the fracture face decreased with decreasing test temperature. Since the welded joint was a double-vee type, the question arose as to whether the shear lip visible on the fracture face was actually shear or whether the fracture occurred in this manner as a result of the joint geometry. Several of the fractures were examined metallographically, and it was found that shear occurred in all cases, even though the fractures followed a particular structure in the heat-affected zone or bond line. The amount of shear was taken as the distance from the surface of the plate to the point where shear disappeared. The decrease in shear lip with decrease in test temperature for the four groups of weldments is illustrated in Figs. 3 through 6. The amount of shear was plotted against test temperature as shown in Fig. 7. The transition temperature was chosen as the temperature at which there was a maximum width of shear lip of 4/64 in. However, as may be seen in Fig. 7, almost any value of shear could have been chosen as a transition criterion without affecting the rating of the weldments. The 4/64 in. of shear was the lowest level that showed a difference between the performance of the four groups of weldments. On this basis, the weldments were rated in the following descending order: Grade 230, austenitic Type 307, Grade 260 and Grade 180. The transition temperatures were: −100° F, −90° F, −80° F and 0° F, respectively. Once again, there is no great difference among the performances of the first three groups of weldments. The weldments prepared with the Grade 180 electrodes continued to exhibit inferior performance. If crack initiation and propagation stages are considered separately, it appears that the shear-lip criterion might be considered a measure of resistance of fracture propagation rather than fracture initiation.

Discussion of Results

The past work in bulge testing of Navy armor and ship steels has shown that the criterion of reduction in plate thickness is a reliable method for evaluating the performance of the explosion-bulge test.[3, 4] In the current study, the base-plate yield strength (157,000 psi) exceeds the yield strengths of the weld deposits (66,000 to 107,000 psi) in every case. Therefore, the yield strength of the deposited weld metals may have greatly influenced

the performance of the weldments because one would expect plastic deformation to occur first in the weld metal in each group of weldments.

The great difference between the yield strength of the base plate and the weld metals may account for the small amount of reduction in thickness in the base plate from the explosive charge. For example, the Grade 180 weldments exhibited very little reduction in plate thickness at the higher testing temperatures (0° to 215° F). In these specimens, most of the deformation took place in the low-yield-strength weld metal. The weld metal deformed until failure, and this failure occurred before the ultimate strength of the base plate was reached. Even though there was very little reduction in plate thickness, the fractures were of shear type at elevated temperature.

In the case of the Grades 230 and 260 weldments, the yield strengths of the weld metals may have dominated the reduction in plate thickness, because the specimens prepared with the higher yield-strength weld metal (Grade 260) exhibited the greater reduction in plate thickness prior to failure. The toughness of the weld metal (measured by Charpy V-notched bars) did not appear to influence the reduction in plate thickness to as great a degree as the yield strength, because the toughness of the Grade 230 weld metal (23 ft-lb at −65° F) is higher than that of the Grade 260 (12 ft-lb at −65° F).

A hardness survey of the austenitic weld metal after testing showed it to be in the range of 140,000- to 150,000-psi tensile strength. With this increase in tensile strength, one may assume that the yield strength would also be increased. Therefore, the good performance of the austenitic welded specimens may be attributed to the increase in yield strength of the weld metal because of work hardening and/or a high strain rate during testing. On the basis that the yield strength of the austenitic and high-strength ferritic weld metals were comparable, it might be assumed that this similarity in strength may be responsible partially for the similar performance of the three groups of specimens in reduction in plate thickness.

The amount of shear lip on the fracture faces of the specimens appeared to be a useful criterion for evaluating the resistance of the weldments to crack propagation. It can be seen from Figs. 3 through

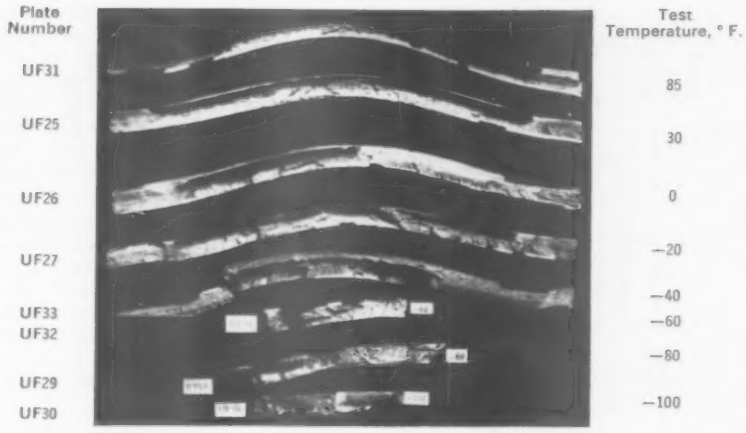


Fig. 3—Fracture surfaces of grade 260 weldments

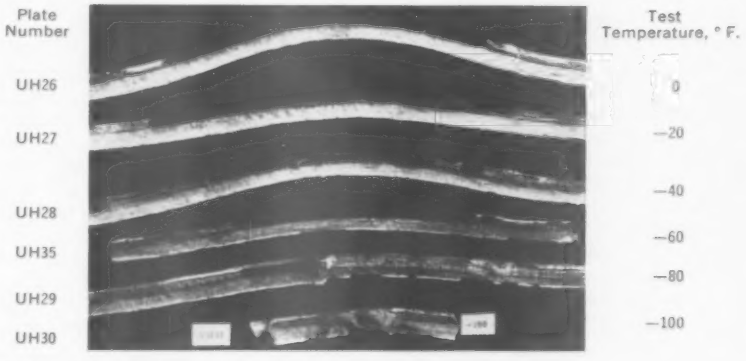


Fig. 4—Fracture surfaces of austenitic type 307 weldments

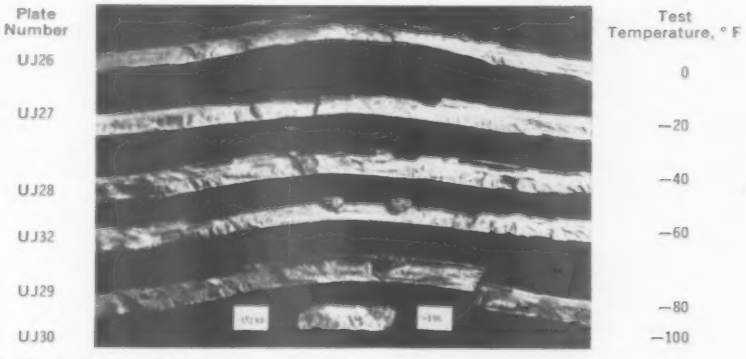


Fig. 5—Fracture surfaces of grade 230 weldments

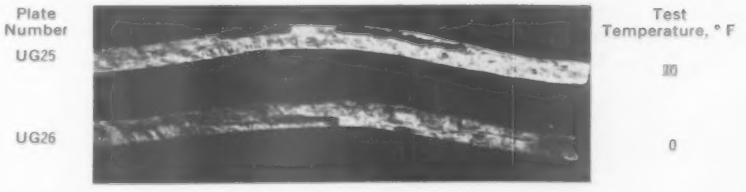


Fig. 6—Fracture surfaces of grade 180 weldments

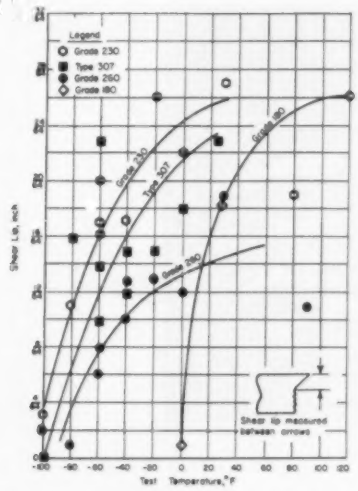


Fig. 7—Test results of explosion-bulge specimens as determined by shear lip. Welds in 1-in. plate

6 that the amount of shear lip decreased as the test temperature decreased. As mentioned previously, there was some doubt as to whether the fracture actually sheared or whether the location and appearance of the shear lip was influenced by the geometry of the joint. The joints that would be of most concern are those prepared with the austenitic electrodes, because many of the failures were in the bond line; however, microscopic examination of the tested specimens showed shear along the fracture face.

Summary

Two methods were used to evaluate the explosion-test specimens. The first method, measuring the amount of reduction in plate thickness, was selected because it appeared to be a useful criterion for evaluating ship-steel weldments, and these measurements could be obtained easily. In addition, this criterion appeared to be a measure of the resistance of the weldments to crack initiation. One fault found with this method of rating the performance of armor weldments was that the reduction of plate thickness was very small (in most cases less than 4%); therefore, a small error in measurement would result in a sizable error in calculating the percent reduction in thickness. The yield strength of the weld metal appeared to influence the results to a great extent because the base plate greatly overmatched all of the weld metals in yield strength. As a result, the weaker the weld metal, the less the base metal deformed prior to failure and the lower the resistance of the weldment to crack initiation. On the basis of the temperature at which the weldments exhibited $^1/_2$% reduction in thickness, a plot of reduction in plate thickness against test temperature rated the weldments in the following descending order: Grade 260, −100° F; austenitic Type 307, −90° F; Grade 230, −80° F; and Grade 180, 110° F.

It was observed that the amount of shear contained in the fracture faces decreased as the test temperature decreased, and in addition, this criterion appeared to be a measure of the weldments' resistance to crack propagation. Therefore, the degree of shear was used as a method of rating the welded joints. This criterion rated the weldments in the following descending order: Grade 230, −100° F; austenitic Type 307, −90° F; Grade 260, −80° F; and Grade 180, 0° F. This rating was based on the temperatures at which the fracture surfaces of the specimens contained a shear lip $^4/_{64}$-in. wide Extreme care had to be used in evaluating the welded joints by this method, because it is difficult to discern whether the fracture occurred in shear or whether it followed the geometry of the bond line. It is possible also, that the amount of shear will vary in different zones of a weldment. Investigations of Navy armor and ship steel[6] indicated that the amount of shear lip may be considered as a measure of resistance to crack propagation of bulge plates prepared from various grades of structural steel. Consequently, the criterion should be of value in determining the performance of welded joints in Army armor tested under similar conditions.

The reduction in plate thickness may be considered as a comparative measure of the resistance of an explosion-bulge plate to crack initiation while shear lip may be used as a comparative measure of resistance to crack propagation. Although the method of measuring these criteria leaves much to be desired, the differences measured by them are believed to be significant and indicate that the explosion-bulge test is useful in determining the ballistic shock performance of armor weldments.

The criterion (inches of cracking) used for evaluating the ballistic H-plate may be considered a measure of the resistance of the ballistic H-plate to crack propagation. The amount of shear on the fracture face of the explosion-bulge plates is also a measure of the resistance of the weldments to crack propagation. In previous studies, H-plates were prepared from the same heat of armor and batches of electrodes that were used in this study of bulge plates. A comparison of the results of the two types of specimens showed that the weldments made with the different types of electrodes were rated in the same order. Therefore, it appears that the explosion-bulge plate may be considered as a partial substitute for the ballistic H-plate.

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Notch-Rupture Strength of Type 347 Heat-Affected Zone

Results of investigation indicate that welds in Type 347 material should always be given a post-weld solution heat treatment for maximum assurance of satisfactory service performance

BY R. J. CHRISTOFFEL

ABSTRACT. The notch-rupture strength of the heat-affected zone in Type 347 weld joints was studied. It was found that, in the as-welded condition, the notch-rupture strength of the heat-affected zone was seriously impaired. However, the loss in notch-rupture strength could be recovered by giving the welded joint a post-weld solution heat treatment. The reduction in notch-rupture strength was attributed to the mechanical strain produced during welding. It was also considered a contributing factor to the service cracking encountered in some Type 347 weld joints.

Introduction

Austenitic stainless steels, principally Type 347, have been used in steam-turbine components and piping systems for a number of years. The over-all service performance of this class of materials has been generally satisfactory. However, some cracking difficulties during service have been encountered as reported by Curran and Rankin[1] and by Fairchild.[2] In some instances, the cracking encountered in a particular installation was so severe that, where operating conditions permitted, the austenitic piping has been replaced with ferrite piping. Thus, the problem can be serious enough to warrant detailed study.

In considering the specific cases of cracking, it was observed that the cracking usually occurred in the heat-affected zone of the base metal, and was sporadic in nature. It also appeared that the cracking was produced during service rather than originating from defects produced during fabrication. In addition, it was observed that, although several different welding procedures were used for fabrication,[3] those weld joints which received a post-weld solution heat treatment were generally free of service cracking. The cause of the cracking has been attributed to stress-concentration effects from physical notches, high external stresses such as bending stresses and residual welding stresses.[1] While these factors appeared to provide qualitative explanations for the cracking, they still did not offer a completely satisfactory quantitative answer.

Recently, Grant, *et al.*, published some results pertaining to the effect of cold work on the high-temperature properties of Type 347 material.[4] These investigators found that, while cold working Type 347 produced a significant increase in yield strength, rupture strength and creep strength, the creep-rupture ductility was drastically reduced. It was speculated that the notch-rupture strength would also be reduced as a result of the cold working. The heat-affected zone in an austenitic weld joint is cold worked or, perhaps, more precisely, hot-cold worked over a range of temperatures during welding. Thus, it is possible that the notch-rupture strength of the heat-affected zone in a Type 347 weld joint may be poor in the as-welded condition. If such were the case, it would be a contributing factor to the cracking which occurred during service in the heat-affected zone of the unstress-relieved weld joints. Therefore, it was decided to conduct an investigation to determine the notch-rupture strength of the heat-affected zone of Type 347 weld joints. The results of this investigation are covered in this report.

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Procedure and Results

The base material used in this investigation was obtained from a Type 347 forging, the dimensions of which were 6 x 10 in. by several feet long. This size forging provided adequate restraint during welding. The chemical composition of the base material is listed in Table 1. The forging was supplied in the solution heat-treated condition. Smooth and notch-rupture bars were machined from the forging to determine the basic notch sensitivity of the material in the unwelded solution - treated condition. The smooth rupture bars had a test-section diameter of 0.253 in. and a gage length of 2 in. The notch-rupture bars had an unnotched diameter of 0.357 in., a notched diameter of 0.253 in. and a 60 deg V notch with a 0.005 in. root radius. The theoretical stress-concentration factor for this geometry is 5.10.

Two 16-in. long grooves were machined in the opposite 10-in. faces of the forging. The grooves were 1 in. deep with a $^1/_8$-in. root opening. One sidewall was perpendicular to the surface; so, the entire notch in the notch rupture bars could be placed in the heat-affected zone parallel to the fusion line. Both grooves were welded with $^3/_{16}$-in. diam low-ferrite 347 electrode whose chemical composition is listed in Table 1. The weld was periodically inspected using liquid-dye penetrant and no defects were found. One welded

Table 1—Chemical Composition, %

		C	Mn	Si	Cr	Ni	Cb	Mo	P	S
347	Forging	0.06	1.5	0.64	18.8	9.5	0.57	...	0.025	0.022
347	Weld	0.08	1.95	0.25	19.43	9.98	0.67	...	<0.020	0.012
16-8-2	Weld	0.06	1.92	0.33	16.00	7.80	...	1.59	0.028	0.018

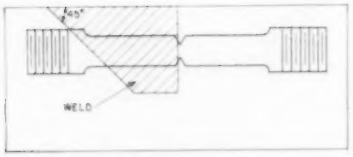


Fig. 1—Sketch showing weld-groove design and location of notch-rupture bar with notch in heat-affected zone

groove was slabbed off the forging and left in the as-welded condition. The remainder of the forging, with the other welded groove, was given a post-weld solution heat treatment consisting of heating to 1100° F, holding for 2 hr, heating then to 1925° F, holding for 2 hr, furnace cooling to 1650°F, holding for 2 hr and air cooling to room temperature. Notch-rupture bars, the same size as given above, were machined from each groove with the axis of the bars transverse to the axis of the groove. These bars were machined in such a manner that the notch was located in the heat-affected zone of the base metal approximately $^{1}/_{32}$ in. from the fusion line. A sketch of the groove design and the location of the notch-rupture bars is shown in Fig. 1.

A macrosection was removed from each welded groove for examination and hardness measurements. The results of the hardness tests, which are the average of five measurements, are listed in Table 2. It will be noted that the hardness of the heat-affected zone in the as-welded condition was roughly 7 points Rockwell "A" harder than the unaffected base metal. In the solution-treated condition, this difference was only about 1 point Rockwell "A" which is negligible.

The microstructure of the base metal in the vicinity of the fusion line was examined. Typical microstructures, in both heat-treated conditions, are shown in Fig. 2 and 3. No difference in microstructure in the base metal was noted at the fusion line compared to some distance from the fusion line in either condition. The dark-appearing

Table 2—Hardness-test Results

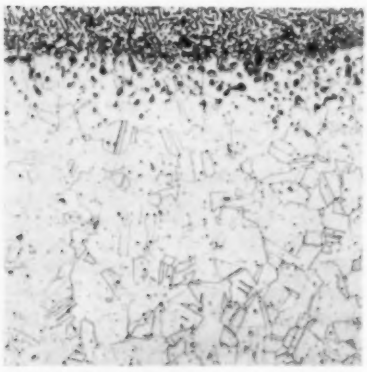
Location	Hardness, Rockwell "A" As-welded	Heat treated
Weld	58	53
Heat-affected zone	54.5	51
Base metal	48	50

phase in the solution-treated sample shown in Fig. 3 at ×100 is actually ferrite which has been attacked by the etchant. The ferrite was not attacked by the mixed acid etchant used for the ×1000 photomicrograph. This phase was identified as ferrite by magnetic-permeability measurements and by etching with 10 *N* NaOH.

Smooth and notched-bar rupture tests from the unwelded material and notch-rupture tests from the weldments in both conditions with the notch located in the heat-affected zone were conducted at 1100 and 1200° F over a time range of roughly 10 to 3000 hr. The rupture-test results are listed in Tables 3, 4, and 5. The 1100° F data are plotted in Fig. 4 and the 1200° F data are plotted in Fig. 5. The rupture strengths for the several conditions at various times and temperatures are summarized in Table 6.

All of the broken notch-rupture bars, for the cases where the notch was located in the heat-affected zone were sectioned parallel to the axis of the bar. The average distance from the weld fusion line to the fracture was measured. These measurements are also recorded in Tables 4 and 5. While there was some variation in this distance, the scatter was not great. Also, the average distance for all test bars from the fusion line to the fracture surface, for both the as-welded and the post-weld solution-treated conditions, was 0.027 in.

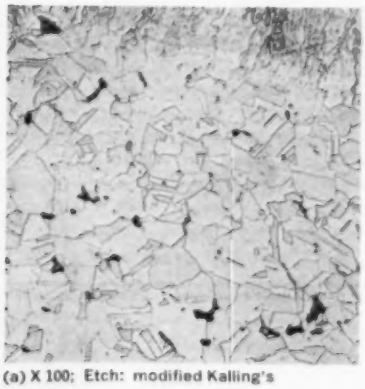
The microstructures of a long- and a short-rupture-life notch bar, tested at 1100 and 1200° F for each of the three notched conditions, were examined. Typical structures at the fracture surface of the notched bars tested for the longest times at 1100° F for each condition are shown in Fig. 6. The microstructural examination showed that the fracture in the notch bars tested in the unwelded solution-treated condition and in the post-weld solution-treated condition with the notch located in the heat-affected zone exhibited good ductility. The fractures were predominately transgranular even for the long-rupture-life bars. Typical structures illustrating the type fracture obtained



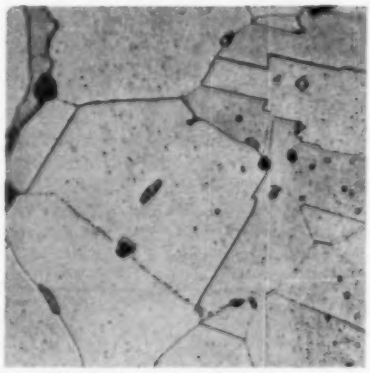
(a) X 100; Etch: 10% oxalic

(b) X 1000; Etch: mixed acids

Fig. 2—Microstructure of heat-affected zone in Type 347 forging. As-welded condition. (Reduced by 40% upon reproduction)



(a) X 100; Etch: modified Kalling's



(b) X 1000; Etch: mixed acids

Fig. 3—Microstructure of heat-affected zone in Type 347 forging. Post-weld solution-heat-treated condition. (Reduced by 40% upon reproduction)

from the bars tested in these conditions are shown in Figs. 6a and 6b. However, the fractures of the notched bars tested in the as-welded condition with the notch located in the heat-affected zone showed little ductility. These fractures were predominately intergranular particularly for the long-rupture-life bars. A typical illustration of the type fracture obtained from bars tested in this condition is shown in Fig. 6c.

Two other supplementary tests were conducted in this investigation which will now be described.

To separate the thermal effects in the heat-affected zone from the mechanical strain effects, four notch-rupture bars were tested in which the material in the vicinity of the notch had been subjected to the thermal cycle produced in the heat-affected zone by welding. This was accomplished by heat treating test bars in the RPI hot-ductility-equipment using just the time-temperature controlling feature of the equipment.[5] The thermal cycle used consisted of heating to a peak temperature of 2300° F and cooling to room temperature. The peak temperature of 2300° F was used since Nippes, *et al.*, reported that that was the peak temperature reached in the heat-affected zone at a distance of 0.030 in. from the fusion line.[6] The distance of 0.030 in. is approximately the average distance from the fusion line where the notch was located in the actual welded samples.

The hardness of the synthetically heat-treated bars, in the center of the heated zone was checked after the heat treatment and found to be essentially the same as it was in the unheated regions. This indicated that no hot-cold working was produced in the heat-treated zone. Notch-rupture bars were machined from these bars with the notch

Table 3—Rupture-test Results; Unwelded; Solution-treated Material

Temperature, ° F	Stress, kpsi	Time, hr	Elongation in 2 in., %	Reduction in area, %
Smooth bar				
1100	50	20.2	18.7	19
1100	45	190	11.9	23
1100	40	1098	8.85	20
1100	37	1322.5	8.4	18
1100	30	3975 +	Test stopped	
1200	40	21.9	10.5	17
1200	35	85	8.85	21.4
1200	30	304	10.8	26
1200	25	341	7.45	19
1200	25	906	5.75	7.8
1200	21	2368	4.3	7.8
Notch bar				
1100	60	11		
1100	55	15		
1100	45	128.5		
1100	40	852		
1100	35	4248		
1200	45	3		
1200	40	34		
1200	37	133		
1200	35	373		
1200	30	696		
1200	25	3000		
1200	22	5800		

Table 4—Rupture-test Results; Notch in Heat-affected Zone; As-welded Condition

Temperature °F	Stress, kpsi	Time, hr	Distance to fusion line, in.
1100	55	14.5	0.044
1100	50	24.2	0.036
1100	42	69.2	0.022
1100	40	115.5	0.029
1100	35	68.5	0.048
1100	30	315.1	0.032
1100	25	1088	0.029
1200	40	14	0.027
1200	35	20.9	0.025
1200	30	74.4	0.024
1200	25	92.4	0.019
1200	23	112	...
1200	22	1135.5	0.008
1200	17	2031	0.006

Table 5—Rupture-test Results; Notch in Heat-affected Zone; Post-weld Solution-treated Condition

Temperature, ° F	Stress, kpsi	Time, hr	Distance to fusion line, in.
1100	65	0.9	0.023
1100	60	31.2	0.036
1100	55	498	0.039
1100	50	864	0.034
1100	45	1736	0.022
1100	40	3826	0.027
1200	50	10.5	0.013
1200	45	87.9	0.026
1200	40	238	...
1200	37	365	0.021
1200	32	1056	0.031
1200	28	1002	0.023

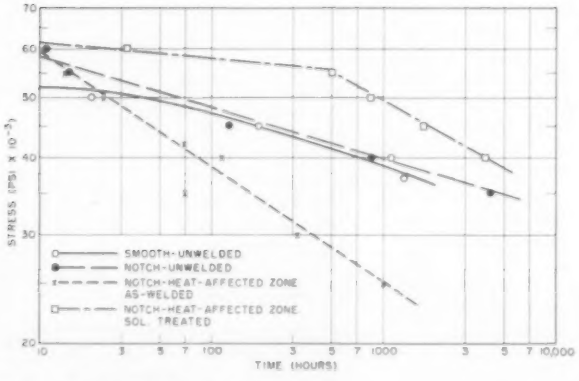


Fig. 4—Rupture-test results at 1100° F

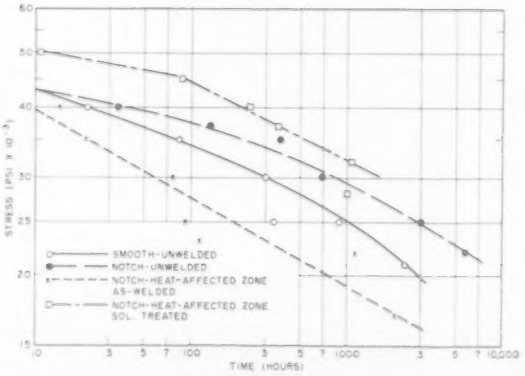


Fig. 5—Rupture-test results at 1200° F

Table 6—Summary of Rupture-test Results

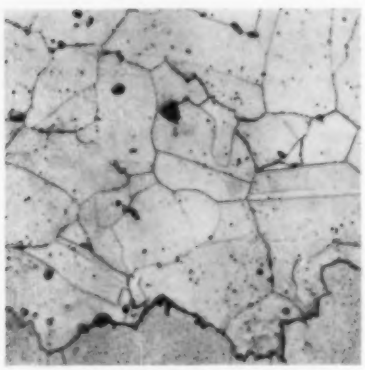
Temperature, ° F	Time, hr	Rupture strength, psi: Smooth, unwelded	Notch, unwelded	Notch heat-affected zone, as-welded	Notch heat-affected zone, sol. treat.
1100	10	52,000	57,500	59,000	61,000
1100	100	47,000	48,000	38,500	57,500
1100	1000	38,500	39,500	25,000	49,000
1200	10	42,500	42,500	39,000	50,000
1200	100	34,000	37,500	27,500	44,000
1200	1000	25,000	29,000	19,000	32,000

located in the center of the heat-treated zone. These bars were tested at 1200° F, and the results obtained are listed in Table 7. These results are plotted in Fig. 7 where the rupture curves shown in Fig. 5 are also reproduced for comparison purposes. It can be seen from Fig. 7 that the two short-time points were somewhat weaker than the unwelded solution-treated notch stength and are comparable to the notch strength of the heat-affected zone tested in the as-welded condition. However, the strengths of the two long-time bars were approximately identical to the notch strength of the unwelded solution-treated material.

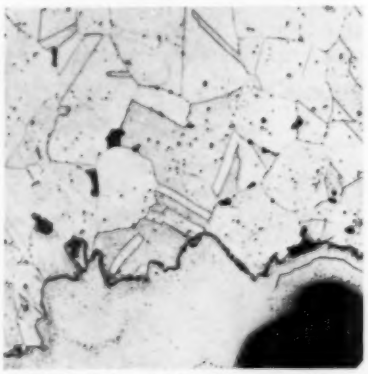
The second supplementary test was conducted to determine if the notch-rupture strength of the heat-affected zone in the as-welded condition would be affected as significantly if 16-8-2 weld metal[7] was used instead of the low-ferrite 347 weld metal. Another groove similar to the one shown in Fig. 1 was welded using $^3/_{16}$-in. diam 16-8-2 electrode. The welded groove was left in the as-welded condition. The chemical composition of the weld metal is listed in Table 1. The hardness of the heat-affected zone in this weldment was measured, and it was found to be essentially the same as that which was obtained when the 347 weld metal was used. Notch-rupture bars were machined from this weldment with the notch located in the heat-affected zone as previously described. The bars were then tested at 1100° F. The results obtained are plotted in Fig. 8.

Table 7—Rupture-test Results; Notch in Synthetic Heat-affected Zone; As-welded Condition, Temperature = 1200° F

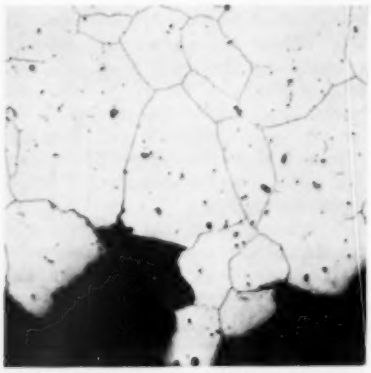
Stress, kpsi	Time, hr
40	6.9
40	16.3
30	692.7
30	730



(a) X 250; Etch: mixed acids; unwelded solution-treated condition; 35,000 psi; 4248 hr



(b) X 250; Etch: mixed acids; post-weld solution-treated condition; 40,000 psi;3826 hr



(c) X 200; Etch: modified Kalling's; as-welded condition; 25,000 psi; 1008 hr

Fig. 6—Microstructures at fracture surfaces of notch bars tested at 1100° F. (Reduced by 40% upon reproduction)

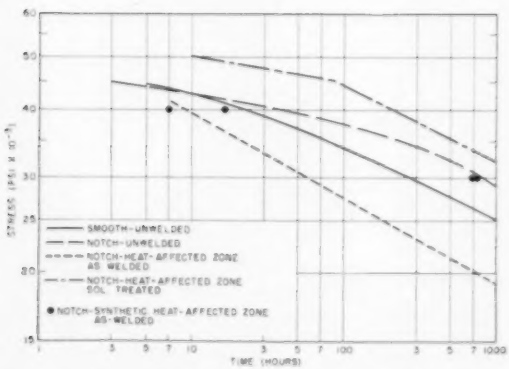


Fig. 7—Rupture-test results of notch bars with synthetic heat-affected zone tested at 1200° F

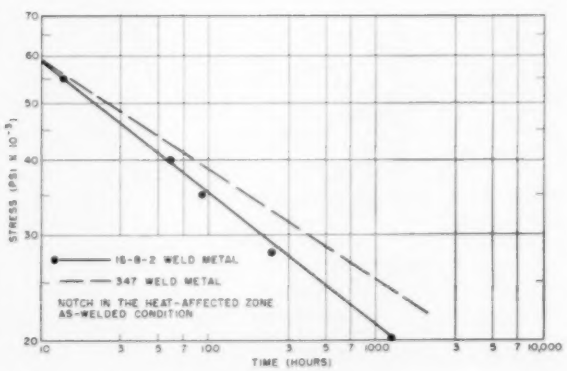


Fig. 8—Notch-rupture-test results at 1100° F

The notch-rupture curve obtained when the 347 weld metal was used and tested in the as-welded condition is also plotted on this figure for comparison purposes. It can be seen from these data that the results obtained with the 16-8-2 weld metal, though slightly lower, were essentially the same as those obtained when the 347 weld metal was used.

Discussion

The results obtained in this investigation will be discussed in two parts. In the first part, the results will be analyzed in themselves, and possible explanations for the observed behavior will be considered. In the second part, the results will be considered as they apply to actual austenitic weld joints in turbine installations.

Analysis of Results

The results shown in Figs. 4 and 5 and in Table 6 indicate that the unwelded 347 material was essentially notch ductile,* although for short times at 1200° F and for intermediate times at 1100° F this condition was borderline. However, in general, it can be considered that, for long-time rupture conditions at 1100 and 1200° F, the unwelded solution-treated material was notch ductile.

It can also be seen from the results that the notch strength of the heat-affected zone tested in the as-welded condition was considerably less than either the notch or smooth strength of the unwelded material. On the other hand, the notch strength of the heat-affected zone tested in the post-weld solution-treated condition was higher than either the notch or smooth strength of the unwelded material. The difference in notch strengths of the heat-affected zone between the two conditions was almost two to one for some cases of time and temperature. Thus, it has been shown that welding drastically reduced the notch-rupture strength of the heat-affected zone in Type 347 material. The loss in the heat-affected zone notch strength produced by welding could be recovered and even improved over the unwelded notch strength by giving the weld joint a post-weld solution treatment at 1925° F.

The first question to be answered is the reason for the observed behavior. The loss in notch-rupture strength in the heat-affected zone in the as-welded condition could be caused by either the thermal cycle or the mechanical strain cycle produced in the heat-affected zone during welding. In a practical sense, it is not possible to separate these two factors since the strain cycle is actually a result of the thermal cycle. It is conceivable, though that the observed results could be caused by some metallurgical change produced by just the welding thermal cycle. However, the results obtained with the notch-rupture samples tested in the "as-welded" condition after being subjected to the welding thermal cycle by the RPI time-temperature controller indicate that the loss in notch-rupture strength is not due to the thermal cycle. The short-time points for the above bars were somewhat inconclusive, but the long-time points, which are more definitive of a material's behavior, show that the welding thermal cycle had essentially no effect on the material's unwelded notch-rupture strength. Therefore, the loss in notch-rupture strength must be due to the mechanical strain produced in the heat-affected zone during welding.

As mentioned in the Introduction, Grant, *et al.*, found that cold working or strain hardening Type 347 material produced an increase in yield strength, rupture strength and creep strength and a decrease in ductility. Since strain hardening was produced in the heat-affected zone of the Type 347 material during welding, it should be expected that the material in this region would have a higher yield strength and creep strength and a lower ductility than the unaffected or unwelded material. Using the concepts developed by Voorhees and Freeman,[5] with regard to notch-rupture phenomena, the higher yield strength and creep strength would tend to maintain the maximum effective stress at a high level above the nominal stress. This condition would lead to rapid expenditure of rupture life and premature failure of the notched bar or lowered notch rupture strength. The lowered ductility would also lead to a brittle-type fracture, as the metallographic examination showed, and shortened notch-rupture life compared to smooth-bar rupture life. Therefore, it appears that the notch-brittle condition and the low notch-rupture strength of the heat-affected zone in Type 347 material in the as-welded condition was the result of the plastic deformation produced in the heat-affected zone by the welding cycle.

It can also be seen from the test results that the use of the 16-8-2 weld metal produced no improvement in notch-rupture strength of the heat-affected zone, compared to the use of the low-ferrite 347 weld metal. This is not surprising since in order for the type weld metal to affect the heat-affected-zone behavior, its stress-strain characteristics would have to be such that it would not strain the heat-affected zone as much during the welding cycle. However, the stress-strain properties of the 16-8-2 weld metal, particularly at low temperatures, are not significantly different from those of the low ferrite 347 weld metal.

The recovery of notch-rupture strength in the heat-affected zone which received a post-weld solution treatment indicates that the 1925° F heat treatment was effective in removing the detrimental cold work produced in the heat-affected zone during welding. The fact that the notch-rupture strength of the heat-affected zone in the post-weld solution-treated condition was greater than the notch-rupture strength of the original unwelded material was somewhat unexpected. There is no apparent explanation for this greater strength unless there was some difference in the effectiveness of the two solution treatments in removing any residual strain hardening in the material.

Application of Results

The results obtained will now be considered as they apply to actual weld joints in turbine installations. The first question which can be asked is whether or not the results obtained using notch-rupture bars are applicable to an actual weld joint. To be sure, the geometrical configuration of the notch-rupture bar and the weld joint are completely different. Of course, there are physical notches present in a weld joint at the fusion line or heat-affected zone region. At the root of the weld, the notch may be very sharp if a conventional-type backing ring is used or relatively shallow if the consumable-type backing ring is used. A minor notch is also present at the top of the weld where the weld is blended into the pipe.

If one considered only the physical notches in the weld joint, particularly with the almost universal present-day practice of using the consumable-type backing ring, the results of this investigation would have little significance with respect to an actual weld joint. However, in an actual weld joint, a "metallurgical notch" is also present at the fusion-line region. This situation arises from the fact that the weld

* The following terms are defined for this report: Notch-ductile behavior—notch-bar rupture strength greater than smooth-bar rupture strength; Notch-brittle behavior—notch-bar rupture strength less than smooth-bar rupture strength.

metal in the as-welded condition has a higher yield strength than even the heat-affected zone. The higher yield strength of the weld metal will restrain flow in the adjacent heat-affected zone material. This restraint of flow produces a stress concentration in the same manner in which the material on either side of the notch root in a notch-rupture bar restrains flow in the notch-root region and produces a stress concentration. Therefore, although the geometrical shapes of the notched bar and the weld joint are different, the results obtained in this investigation are considered applicable to weld joints because the metallurgical notch at the fusion line in the weld joint can produce a stress concentration condition in the same manner as a notch bar.

A second point to consider is an explanation for the fact that the heat-affected zone did not show up as "poor" in the conventional cross-weld smooth-bar tests previously conducted. It should be realized, however, that in a small-diameter uniformly loaded round bar failure does not necessarily occur in the weakest region, since narrow regions in the bar are not free to behave independently of the rest of the bar. Actually, in a small-diameter smooth bar, failure usually occurs in the region which first yields. In a cross-weld austenitic-weldment test bar in the as-welded condition, this would usually occur in the base metal some distance from the fusion line. Thus, the heat-affected zone region is not completely tested.

Also, in a conventional smooth rupture bar whose diameter is 0.253 in., there would not be sufficient restraint to produce much of a stress concentration at the fusion line. Therefore, if the heat-affected zone was only "poor" under the influence of a stress concentration, this would not be determined in a smooth-bar cross-weld test. Actually, if it is desired to determine if a material, or a region in a material, is brittle, it must be tested in such a manner that, if it is brittle, it can fail in a brittle fashion in the region of interest. This condition is not met in the conventional smooth-bar rupture specimen while it is, of course, in the notch bar. Of course, in an actual pipe weld joint, there is sufficient size to develop the restraint necessary to produce a stress concentration in the heat-affected zone. Therefore, the conditions for a notch-brittle behavior, if the material should be notch brittle, would also be met in a pipe weld joint.

The third question which can be raised with regard to the results is to whether they are typical of the behavior of all heats of Type 347 material. From a factual basis only, one heat of 347 was tested; so, all that can be stated positively is that this is the behavior of just one heat. However, several indirect observations can be made and applied to answer this question. First of all, considerable welding was done on the 347 forging used in this investigation and no cracking has been encountered. Thus, this particular forging was not a "poor" heat from the welding standpoint. Secondly, to determine how typical or average this particular 347 forging was, its smooth-bar rupture strength and rupture ductility were compared with the scatter bands for these properties obtained from published data for many heats of 347 material.[4] This comparison showed that the rupture strength and rupture ductility of the forging material fell in the center or upper half of the scatter bands. Thus, it can be concluded that the heat of 347 material used in this investigation was a typical heat of 347. Therefore, it should be expected that since a loss in notch-rupture strength in the heat-affected zone in the as-welded condition occurred in this typical heat of 347, that a similar behavior should also occur in all heats of 347 differing perhaps only in degree. However, to determine more definitely if the results found in this investigation are typical of 347 in general, it is planned to conduct similar studies using two other heats of 347 material. Studies are also being made of this behavior in Type 316 material.

Conclusions

The results obtained in this investigation show, for the first time, that the heat-affected zone of a sound weld joint (that is, not considering those cases where actual cracking is produced in the heat-affected zone during welding because of poor hot ductility) in 347 material in the as-welded condition has properties inferior to the unwelded material or the post-weld solution-treated heat-affected zone. It is likely that the low notch-rupture strength of the heat-affected zone was a contributing factor to the cracking which occurred in this region in the pipe weld joints mentioned in the Introduction. It is not considered that this is the only cause of the cracking, since the notch-rupture strength would still be well above the average service stress of approximately 5000 psi. However, in the presence of residual welding stresses at a high level or bending stresses and the service stresses, the low notch-rupture strength would be the final contributing factor leading to premature failure.

The desirability of giving completed weld joints in Type 347 material a post-weld solution treatment is also emphasized from these results. It can be seen now that the post-weld heat treatment, in addition to solutioning and spherodizing ferrite in the weld metal and relieving the residual welding stresses, also improves the notch-rupture strength of the heat-affected zone. Thus, welds in Type 347 material should always be given a post-weld solution heat treatment for maximum assurance of satisfactory service performance.

Acknowledgment

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Note: When this paper was written, the authors included information and expressed opinions believed to be correct and reliable. Because of the constant advance of technical knowledge, the widely differing conditions of possible specific application and the possibility of misapplication of the contents of this paper must be at the sole discretion and responsibility of the user.

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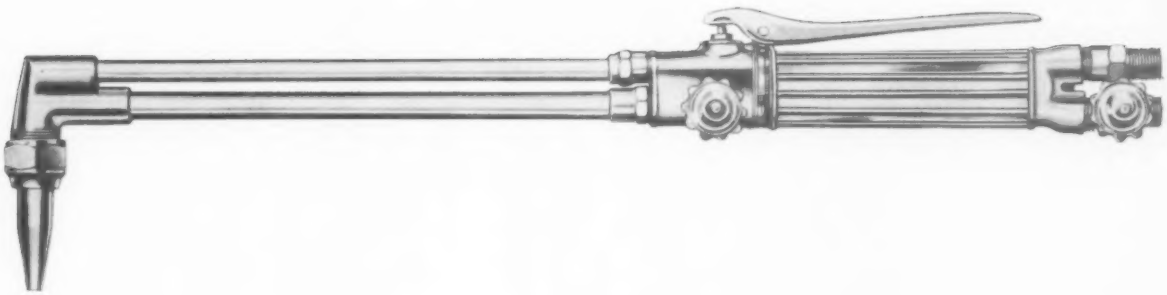

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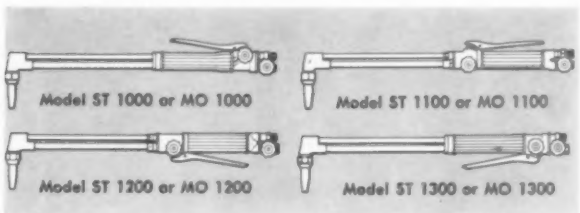

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